

Best Practices for Data Publication in the Astronomical Literature

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ABSTRACT

We present an overview of best practices for publishing data in astronomy and astrophysics journals. These recommendations are intended as a reference for authors to help prepare and publish data in a way that will better represent and support science results, enable better data sharing, improve reproducibility, and enhance the reusability of data. Observance of these guidelines will also help to streamline the extraction, preservation, integration and cross-linking of valuable data from astrophysics literature into major astronomical databases, and consequently facilitate new modes of science discovery that will better exploit the vast quantities of panchromatic and multi-dimensional data associated with the literature. We encourage authors, journal editors, referees, and publishers to implement the best practices reviewed here, as well as related recommendations from international astronomical organizations such as the International Astronomical Union (IAU) and International Virtual Observatory Alliance (IVOA) for publication of nomenclature, data, and metadata. A convenient *Checklist of Recommendations for Publishing Data in Literature* (Appendix A) is included for authors to consult before the submission of the final version of their journal articles and associated data files. We recommend that publishers of journals in astronomy and astrophysics incorporate a link to this document in their Instructions to Authors.

Keywords: editorials, standards — astronomical databases: miscellaneous

1. INTRODUCTION

Modern telescopes and instruments are being used to observe larger areas of the sky over wider ranges of the spectrum, and with greater frequency than ever before. The volume and complexity of resulting data are growing at an exponential rate, not only within the astronomical archives that capture the original data products,

but also in the scientific literature where more highly-processed data are published alongside scientific results. It is therefore extremely important that data appearing in journal articles are prepared and published with great diligence in order to: accurately present new data, avoid any loss of data, preserve and support the integrity of scientific results, and enhance the reusability of data

to facilitate further analysis and followup studies. The impacts of publishing complete and accurate data are far-reaching across all astrophysical disciplines and encompass all types of objects, and are important to the scientific process for providing transparency and reproducibility in the primary record of scientific exploration and discovery.

These data also serve another vital function in modern science as they are continuously being integrated into astronomical archives to provide comprehensive information for astronomical objects, and to support planning new observations, performing data analysis, making new discoveries, and preparing publications of new results. Uniformity and adherence to established norms in published data are essential to improving automation, efficiency, and accuracy of procedures required to integrate data from the literature into astronomical archives in a timely fashion. The high degree of connectivity between the digital journal articles and the astronomical archives, with the NASA Astrophysics Data System (ADS¹) as a nexus through its extensive bibliographic database, provides an ecosystem used 24/7 by thousands of scientists around the world who depend on astronomical data that are as current and accurate as possible.

Much of data appearing in the astronomical literature are presented with great care and serve two scientific needs well: 1) a high quality scientific record with results that can be reproduced and expanded upon in follow-up studies, and 2) clean data that can be straightforwardly integrated into astronomical databases. However, there are a substantial number of journal articles published each year where this is not the case. Various issues continue to severely detract from the quality and utility of the data and hinder both scientific goals. The most common and severe example is the publication of ambiguous object names, typically truncated coordinate-based names, that make it nearly impossible to reproduce observations or accurately cross-identify these sources with those in other journal articles or catalogs. Other common examples include publishing data without uncertainties or with an unrealistic number of significant figures, not specifying the reference frame for coordinate or redshift measurements, and placing data critical to (re)producing science results in a personal URL that has no long-term access support. One study has shown that in 2011, 44% of data links published in the astronomical literature a decade earlier (in 2001) were broken (Pepe et al. 2014). Most of these issues, and more, can be avoided or minimized with a small amount of additional

effort on the part of authors, who are ultimately responsible for the quality of any published work, combined with more attention to flagging such issues by referees and editors so authors can correct errors and omissions before the article is published. To assist in this process, we provide in this article recommendations on best practices for publishing data and metadata in astronomical journals. The topics discussed here are essential to achieving the goals of data sharing, open access, and reproducibility of science results.

Active and consistent participation from authors in presenting their (meta)data in the literature is also crucial for the publication record and to facilitate integration into astronomical information systems (Schwarz 2005). A number of issues discussed here have also been addressed by Cambr esy et al. (2011) in the context of the SIMBAD² and VizieR³ services of CDS⁴. We encourage all authors, referees, editors and publishers to follow these best practices during the preparation, submission, refereeing and editing stages of the publication process. We expect that these best practices will evolve as new forms of data are published in the journals, and as the journals and archives receive feedback from authors. When enough revisions build up, we plan to publish updates to this original publication on arXiv.org. The broader topic of standards, formats and best practices for depositing specific types of data products in repositories and archives is beyond the scope of this article.

2. ASTROPHYSICAL DATA GUIDELINES

Here we provide guidelines for presenting data in many areas of astrophysical research: stars, galaxies, dust and gas, planets. Names, astrometry, photometry, redshift/velocity etc. are among the fundamentals of the data published in an astrophysical article. Formatting and referencing these data correctly are essential in understanding the data itself and the derived science results. Before addressing each of these categories individually, here are some general rules:

- **Define symbols, acronyms, and abbreviations.** Symbols, acronyms, and abbreviations must be clearly defined when used anywhere in a publication, generally at first use, even if they are common throughout the discipline. This is especially important in younger fields of investi-

¹ <https://ui.adsabs.harvard.edu/>

² Set of Identifications, Measurements and Bibliography for Astronomical Data; <http://simbad.unistra.fr/simbad/>

³ <http://vizier.unistra.fr/vizier/>

⁴ Centre de Donn ees astronomiques de Strasbourg; <https://cds.u-strasbg.fr/>

gation where symbols may be used in divergent ways by the community such that their meaning is not as clear as it might seem. If there is any doubt, define everything explicitly, or at the least cite a source which clearly defines the conventions adopted. The definition should be consistent through the entire article to avoid confusion.

- **Provide uncertainty and confidence level when reporting a new measurement.** Avoid using parentheses after the last digits of the measured value to indicate uncertainty, as this is very unclear with a high degree of probable confusion. For example, when the period of a periodic phenomenon is represented as “P = 1.23456(12) days”, the uncertainty should be interpreted as “ ± 0.00012 days”, but may be misinterpreted as “ ± 0.0000012 days”.
- **Present the appropriate number of significant figures for numerical measurements and uncertainties.** Significant figures in a measurement indicate its precision. When data are generated from floating-point machine computation, there is a tendency to display more significant figures than are justified by the measurement. A decimal degree coordinate of (131.32134587°, 0.01243229°) would imply an accuracy of 10^{-8} degrees (or 0.00001”), which is not obtainable by most current telescopes. Therefore it is very important for the authors to always supply data values that are appropriate to the measurement significance, and coordinate the number of decimal places in both the measurements and uncertainties. The rightmost significant figure of a measurement should correspond to the rightmost significant figure of its associated uncertainty. For example, the measurement 0.123456789 of some quantity $Q \pm Q_{err}$ should be rounded to 0.123 if the associated uncertainty Q_{err} is 0.002.
- **Adopt commonly-used units wherever possible.** This will not only prevent the readers from possibly getting different values using different conversion factors, but also facilitate the comparison between results from various observations, models, or analyses.
- **Indicate preferred values if applicable.** When reporting multiple measurements for one parameter or alternative parameter sets from different techniques or algorithms that fit observations, it is valuable to the readers and beneficial

to the archives that the authors indicate the preferred value or parameter set.

2.1. Nomenclature

The most common and basic type of data in any observational article is the naming of astronomical sources. Unambiguous names that follow recommended nomenclature standards are essential prerequisites for clear communication of observational results and scientific conclusions, and to ensure that follow-up observations target the proper source.

2.1.1. IAU conventions

When assigning object names in an article, we recommend the authors follow the established conventions from the International Astronomical Union (IAU⁵), such as “How to refer to a source or designate a new one”⁶ and “Specifications concerning designations for astronomical radiation sources outside the solar system”⁷. The IAU Dictionary of Nomenclature of Celestial Objects⁸ provides a list of acronyms that are currently in use, and should be consulted to confirm the correct acronyms and formats for known objects, and to avoid reusing the same ones for newly discovered objects.

Stellar names should follow the IAU naming conventions on the naming of stars⁹. The naming of double stars or common proper motion systems and their components should follow the rules of the Washington Double Star Catalog (WDS¹⁰; see also Hartkopf & Mason 2004). We note, however, that the scheme followed by multiple system descriptors should not be applied to stellar names, though there are a few exceptions - for the components only - for some historical acronyms (e.g., HD, DM). Especially, do not name a secondary component of a wide common proper system HD ...B if the component itself has its own HD name. For double stars resolved in astrometric catalogs, the identification of both components should be given (e.g., WDS ...AB = HD ..., WDS ...A = TYC ...-1, WDS ...B = TYC ...-2).

Letter designations for confirmed exoplanets in multi-planet systems should be in discovery order, and typically in the order of ascending period when more than one of the exoplanets is announced in a single paper¹¹.

⁵ <https://www.iau.org/>

⁶ <https://cdsweb.u-strasbg.fr/Dic/how.html>

⁷ <https://cds.u-strasbg.fr/Dic/iau-spec.html>

⁸ <https://cds.u-strasbg.fr/cgi-bin/Dic-Simbad>

⁹ https://www.iau.org/public/themes/naming_stars/

¹⁰ <https://www.usno.navy.mil/USNO/astrometry/optical-IR-prod/wds/WDS>

¹¹ https://www.iau.org/public/themes/naming_exoplanets/

When publishing simultaneous independent discovery announcements of the same astrophysical objects, reasonable efforts should be made to coordinate and avoid publishing conflicting designations.

Following the IAU guidelines, we recommend:

- **Provide the complete object name.** A name that has the coordinate part truncated will likely be ambiguous and can be confused with a nearby object. See Table 1 for examples.
- **Explicitly include the “J” in names based on J2000 coordinates.** Without the “J”, this could be misinterpreted as B1950, resulting in an incorrect object position and telescope pointing.
- **Insert spacers between a catalog name and the identifiers within the catalog.** For example, use B3 2327+391, not B32327+391. This will prevent mixing and misinterpreting the catalog name and the identifiers, and allow both the readers and name resolver services at the archives (e.g., SIMBAD, NED¹², NASA Exoplanet Archive¹³) to recognize object names more efficiently.
- **Distinguish between part of an object and the object itself.** For example, use “3C 295 cluster” instead of “3C 295” when referring to the cluster. Similarly, the hosts for transients, like supernovae and gamma-ray bursts, should be referred to with the proper names when host properties are discussed, instead of just using the names of the transients.
- **Do not use the same name for different objects.** Once a name has been assigned to an object in a published catalog or journal article, it should not be reused for a different source in the future, even if an object’s existence is refuted. For example, the tau Ceti system now has four planets: e, f, g, and h. Since tau Ceti b, c, and d were refuted, the letter designations b, c, and d were not reused for the newer planets to avoid confusion.

Table 1 illustrates some ambiguous/improper astronomical designations that have appeared in the literature, along with the recommended proper usage.

2.1.2. *New objects*

¹² NASA/IPAC Extragalactic Database; <https://ned.ipac.caltech.edu/>

¹³ <https://exoplanetarchive.ipac.caltech.edu/>

For newly discovered objects, please follow the IAU conventions mentioned in §2.1.1 for designations. Additional recommendations include:

- **Always assign a name.** Without a proper name, it is difficult for both the readers and the databases to unambiguously reference information in a publication.
- **Verify the name is unique.** The key to object designations is that each one must be unique when compared to objects identified at other observatories and wavelengths, especially within the same article. When creating new acronyms, please consult the IAU Dictionary of Nomenclature of Celestial Objects as noted in §2.1.1 to avoid reusing existing ones.
- **Keep the appropriate number of significant figures in coordinate-based names.** When the name of an object is generated from the coordinates of the object, too many significant figures would imply a much higher accuracy than the measured position of the object. For example, J092712.64+294344.0 indicates a positional accuracy of 0.15 arcsec while J092712.644+294344.02 indicates an accuracy of 0.015 arcsec. Conversely, it is very important to include all significant figures in coordinate-based source names, at least the first time mentioned in the article, because truncating coordinates often leads to ambiguity and difficulty cross-matching the source with prior data due to confusion with nearby objects.

2.1.3. *Known objects*

For objects that are already published and known, we recommend:

- **Use established names.** It is unnecessary and often adds confusion to give a new name to an object that already has a name. Using the established names also gives proper credit to the original authors or survey team that first discovered and cataloged the source.
- **Check for the correct formatting.** For astronomical objects outside the Solar System, authors are encouraged to validate all the identifiers for known objects in their publications through Sesame¹⁴, a service hosted by CDS that queries NED, SIMBAD, and VizieR to help resolve object names. If some valid names are not indexed

¹⁴ <http://cdsweb.u-strasbg.fr/cgi-bin/Sesame>

Table 1. Examples of improper astronomical designations in literature

As published	Why it is improper	Recommended usage (notes if available)
SDSS J1441+0948	Insufficient precision in RA and DEC can cause confusion with nearby sources.	SDSS J144157.24+094859.1, or SDSS J144156.97+094856.5, or SDSS J144157.26+094853.7
SN 05J	Incomplete name can be interpreted into different objects.	SN 1905J, or SN 2005J
HESS J232+202	Leading zero in RA is missing and can cause misinterpretation of the RA at 23 hours instead of 02 hour.	HESS J0232+202
BR 0529-3526	Missing letter J to specify J2000 equatorial coordinates.	BR J0529-3526
0008+006	Name prefix is needed to distinguish between different objects.	ZC 0008+006 ($z = 2.3$), or IVS B0008+006 ($z = 1.5$)
DEM45	H II regions in LMC or SMC should be indicated with “L” or “S” to avoid ambiguity.	DEM L 045, or DEM S 045
SDSS 587729386611212320	Database objectID numbers are used without specifying release number. The same running number may refer to a different source in a different release.	SDSS DR6 587729386611212320
Gaia DR 2 2.7904e18	ID is written in scientific notation, making it impossible to retrieve the actual object.	Gaia DR2 2790494815860044544

by these services, authors should verify the names with the discovery papers of the objects.

2.1.4. *Cross-identifications*

When multiple designations exist for the same object, the different names are cross-identified by authors or databases. The best practices with these cross-identifications are:

- **Confirm the names and positions.** Many examples exist in the literature where multiple columns of cross-identifications disagree with each other or with the listed coordinates. We suggest to always verify with established databases that all of the names given to an object are valid cross-identifications for the object and that the listed positions are for the same object.
- **Cross-match the same objects within the same article.** If the same object appears in multiple tables of the same article, but with different designations (e.g., duplicated detections at the borders between two tiles of a mosaicked image), a cross-matching of the tables should be done by

the authors to enable the readers to quickly access related data about the objects.

2.2. *Astrometry*

One of the primary attributes for an astronomical source is its location in the sky. Accurate celestial coordinates for the objects are especially important for followup observations and study. When presenting coordinates in a publication, we recommend:

- **Provide the best available coordinates.** Precise positions of the sources are indispensable for the usability of observational data and for planning followup observations. All objects studied in an article, especially those from private catalogs, need to be presented with coordinates. Complete celestial coordinates are preferred. When positional offsets are published instead, it is essential that authors include the coordinates of the reference position, as well as the angle of rotation (if North is not up or East is not to the left), and the sense of the offset (i.e., reference point minus source, or source minus reference point).

- **Specify the celestial reference system and/or frame.** Indicate the reference system and/or frame for the coordinates (Urban & Seidelmann 2013, chap. 4 and 7). The current IAU celestial reference system is the International Celestial Reference System (ICRS¹⁵), and it is realized through the International Celestial Reference Frame (ICRF¹⁶).
- **Indicate the equinox and epoch of observations when necessary.** This is particularly important for the positions of stars and exoplanet systems. Nearby stars can have a quite significant proper motion (>1 arcsec/year), which means that the position changes with time and therefore requires the equinox and epoch of observation in order to compute its position at another epoch. The standard equinox and epoch currently in use are J2000.0 (Aoki et al. 1983).
- **State the wavelength range from which astrometry is obtained, where appropriate.** Astronomical sources can be detected at slightly different positions at different wavelengths due to different emission mechanisms of different components in each band. Therefore, providing the wavelength range of the detection is important for understanding the various components of the object and for cross-identifications between sources detected at various wavelengths.

2.3. Photometry

The flux or intensity of light radiated by astronomical objects is another key observable in astronomy. To properly represent the photometry data and to enable easy comparisons of the results, we strongly recommend:

- **State the facility, telescope and instrument used.** Specify whether the facility is ground-based or space-based. Authors also need to provide any other relevant instrument configuration information, the specific camera on the instrument, and/or the specific CCD chips of the camera that were used in the analysis. These are crucial to the proper interpretation of the data. Good documentation of the metadata will also facilitate the correct and fast ingestion of photometry data in services such as the NED Spectral Energy Distribution (SED) plots and the VizieR Photome-

try viewer¹⁷, which in return will better serve the community.

- **Describe the method used to estimate photometry.** Indicate if an estimate is from point spread function fitting, aperture photometry, isophotal measurements, etc. If it is aperture photometry, report the size of the aperture and background annulus, and any corrections made in the calculation.
- **Use standard passband/filter identifiers.** Do not modify or abbreviate the identifier as it may conflict with a different standard identifier. For example, indicate “Johnson B” or “Cousins B” instead of just “B”; use “2MASS K_s” instead of just “K”. A listing of commonly-used identifiers is available at the Spanish Virtual Observatory Filter Profile Service¹⁸. When possible, authors should provide a link to the instrument documentation with the actual response curve for the filter in question.
- **Clarify the magnitude system.** Explicitly indicate whether a magnitude is on the AB, Vega, STmag, or some other magnitude system.
- **Specify spectral transitions completely.** Describe the molecular species, transitions, and frequencies/wavelengths. For example, carbon monoxide (CO) has several detectable transitions as do ¹³CO and C¹⁷O. The most commonly observed transition is (1-0) and each is between 110 and 115 GHz. To clearly define a spectral transition, one should use, e.g., “CO(1-0) $\nu = 115$ GHz”.

2.4. Time

Knowing the time of observation is essential to understand the observed properties of many astronomical objects, and often for calculating positions, especially for transient or variable sources and moving objects. Calibrations sometimes may also vary depending on when the instrument was installed on a telescope. Authors are advised to:

- **Provide the time of observation and exposure time.** Any times should be explicitly described in terms of both the frame of reference (e.g., JD, BJD, HJD), and the time system used (e.g., UTC, TDB, TAI). For example, use “BJD-TDB” to indicate Barycentric Julian Date in the

¹⁵ <https://www.iers.org/IERS/EN/Science/ICRS/ICRS.html>

¹⁶ <https://www.iers.org/IERS/EN/DataProducts/ICRF/ICRF/icrf.html>

¹⁷ <http://vizier.unistra.fr/vizier/sed/>

¹⁸ <http://svo2.cab.inta-csic.es/theory/fps/>

Barycentric Dynamical Time standard (preferred). This is particularly important when precise timing is needed, such as the measurement of exoplanet transit timing variations. See [Eastman et al. \(2010\)](#) and [Urban & Seidelmann \(2013, chap. 3\)](#) for a helpful discussion of precise time standards. It is also important to specify the duration (exposure time) and whether the presented observation time is the beginning, midpoint, or end of the exposure time. When a precise time is not meaningful (such as detections from stacked images), a time range where these observations occurred should be provided.

- **Favor full Julian Dates over abbreviated or offset Julian Dates.** When reporting Julian Dates, the full unmodified date (e.g., 2456789.123) is preferred over any offset variation (e.g., 6789.123), to avoid confusion. This also helps archives avoid having to track down and add often arbitrary offsets to put observations on a uniform time scale, which can add an opportunity for errors to be introduced. Where an offset variation must be used, be sure to clearly indicate what the offset is (e.g., JD-2454833.0). Note that Modified Julian Date (MJD), although formally defined as the Julian Date minus 2400000.5, is prone to ambiguity. The IAU has recommended “that where there is any possibility of doubt regarding the usage of Modified Julian Date, care be exercised to state its definition specifically.” (Resolution B1, 1997¹⁹).
- **Include phase timing measures along with reported periods, where relevant and practical.** This allows for future observations to be phased against your data, and combined. For example, for a transiting exoplanet orbit where the period is known, include a time of transit.
- **State when observations from multiple missions are executed simultaneously.** Coordinated observations in high-energy astronomy are critical for making a simultaneous spectral fit, which can help determine the physical processes responsible for emission in a particular energy band. It is also important to specify which instruments/cameras/chips were taking data and analyzed during these coordinated observations. If possible, include a graphical representation of the

times that the missions obtained the data to help visualize where the simultaneity occurs.

2.5. Redshift/velocity

The redshift or the recessional radial velocity of an object is of major importance to many astrophysical fields. For various astrophysical reasons, there may be the need for an author to present redshifts in a galactocentric or Local Standard of Rest (LSR) reference frame or some other system. The recommendations on publishing redshift/velocity data include:

- **Describe the method used to obtain redshift.** This includes the particular method (spectroscopic, photometric, Friends-of-Friends, etc.) and base assumptions used in the models (template fitting, machine learning, etc). When available, include a reference to the model/method used to determine the redshift.
- **Specify the reference frame of the redshift measurements.** Be sure to include a clear indication of the reference frame (e.g., heliocentric, barycentric, Galactocentric, LSR). Additional definition on the solar velocities adopted and likely also the knowledge of the Sun’s distance to the Galactic center is needed for Galactocentric velocities.
- **State the convention when redshifts or recessional velocities are listed.** In radio astronomy, redshift is commonly defined as $z = (f - f_0)/f_0$, where f_0 is the rest frequency and f is the observed frequency. Whereas optical astronomers tend to use $z = (\lambda - \lambda_0)/\lambda_0$, where λ_0 is the rest wavelength and λ is the observed wavelength. These two redshift values can differ significantly, especially for large values of z .
- **Provide the wavelength range of the measurement.** When the observations are made with multiple instruments, it is important to clarify at which wavelength the measurement is obtained.
- **Indicate the quality of the measurement when possible.** A qualitative assessment of the quality of a measurement may add useful information for readers and for databases in guiding researchers to use the measurement appropriately in their analyses. Examples include indications of poor seeing or blended objects, uncertain deblending of spectral lines, redshifts based on a single spectral line assuming identification of the proper feature, etc.

¹⁹ https://www.iau.org/static/resolutions/IAU1997_French.pdf

2.6. Classifications

There are many spectral and morphological/phenomenological classifications for astronomical objects, and these classifications are constantly evolving. We suggest:

- **Utilize established classifications as available.** For basic morphological types, use the well-established schemes²⁰. Authors are encouraged to refer to NED’s extensive suite of searchable galaxy classifications and attributes²¹ or SIMBAD’s Object Classification²² which have been standardized to enable unified queries across journal articles and catalogs.
- **Define new classifications clearly.** If new classifications must be created, define them clearly so they can be easily adopted by other researchers, and quickly integrated into databases.

2.7. Orbital parameters

Reports of measured orbital parameters often suffer from ambiguity in terminology used because the conventions used are not clear. It is advised to avoid ambiguous terms, and to explicitly define all terms and symbols wherever there is any possibility of confusion. For instance:

- **Avoid using the term “longitude of periapsis” (or periastron) when “argument of periapsis” (or periastron) is really the term intended.** Only use “longitude of periapsis” when referring to the sum of the argument of periapsis and the longitude of the ascending node.
- **Be explicit about which body’s orbit a measured argument (or longitude) of periapsis refers to.** The argument of periapsis for a planet or a secondary star’s orbit differs from that of the host or primary star’s reflex motion by 180 degrees. Note also that the quantity is affected by the sign convention adopted in radial velocity analyses: as a general rule, positive radial velocity should indicate redshift, and negative should indicate blueshift.
- **Include time of periapsis as appropriate when reporting orbital elements.** For example, when reporting timing for a non-transiting eccentric orbit for which argument of periapsis is

measured, report time of periapsis in preference to (or in addition to) time of inferior conjunction. Both are preferred if possible.

3. DATA PRESENTATION

3.1. Tables

Observational data are often published in the form of tables in an article. For tabular data presentation:

- **Provide a clear title and unambiguous labels of columns.** Indicate the units for each column when applicable. This is especially important when data are to be compared, or used outside a specialized field.
- **Explain the content of each column.** A column should be homogeneous and should not mix different measurements with different units nor errors with limits or comments. Clarify all special symbols or flags in a column, and give references to cited values.
- **Use clearly defined nulls for missing values.** It is recommended to use null values that are documented by widely-used toolkits, e.g., “NaN” for Astropy²³. Avoid using numerical values such as “-999” or “0.0” for missing values as they could be misinterpreted as actual measurement by software. Use only one null value and have a separate field for the reasons of a missing value, instead of having multiple null values to indicate the different reasons.
- **Accompany a machine-readable table with standard README file.** The CDS document “Astronomical Catalogues and Tables Adopted Standards”²⁴ serves a good example of how to generate a standard README file.

For tables containing astronomical objects, it is preferred that authors give the complete names of the objects (§2.1) in each table, and keep the same names in all the tables and text throughout the article when possible. This will not only enable the readers to quickly access related data about the objects, but also greatly expedite the linking and ingestion of data into data archives. The coordinates of the objects (§2.2) should be given in the table where the objects are first presented.

We recommend not to use LaTeX for large tables as the markups degrade the reusability of that data. Authors can improve the transfer of results by avoiding

²⁰ e.g., http://en.wikipedia.org/wiki/Galaxy_morphological_classification

²¹ <https://ned.ipac.caltech.edu/uri/NED::Classifications/>

²² <http://simbad.u-strasbg.fr/guide/otypes.htx>

²³ <https://www.astropy.org/>

²⁴ <http://vizier.u-strasbg.fr/vizier/doc/catstd.htx>

elaborate LaTeX tricks and treating inline tables as regular data arrays. For instance, method or other qualifying note marks could be given numerical values and displayed in an additional column instead of using table note marks which are not easily parsed by a machine. Additional details of the table should be included in an accompanying metadata file (see 4). Authors are also advised to report important numerical results for more than a couple of data points in tables, not just in text. When a number is reported in both text and a table, make sure it is consistent in both places.

3.2. Figures

Figures are commonly used for data visualization in an astronomical article, especially for images, spectra, SED plots, etc. For figures in a publication, we recommend:

- **Provide clear caption, legend and axis labels for each figure.** Describe in detail what is presented in the figure, what different colors, symbols, and lines represent. Units of the axis labels should be included when applicable.
- **Create the graphics with accessibility in mind.** Accessibility should be taken into consideration when designing the graphics as it will help a broader audience to properly understand the information conveyed in these plots. For example, color-blind users would benefit from symbols that vary in shape in addition to colors. See the AAS²⁵ journals’ graphics guide²⁶ for more advice on this.
- **Include information for “data behind the plots”.** Make public the original data files used to generate the figures, as this will greatly enhance the ability to reproduce/validate or build upon published results.

4. DATA ARCHIVING AND ACCESS

To ensure long term preservation, access, and reuse of data published in the literature, data products should be made available to readers and for data integration services. This applies to both data from original observations and enhanced products derived from previously published and/or archival data. We ask authors to:

- **Append small data sets as part of the publication.** Preserve data as supplementary materials with your final journal article, or post the data files with your arXiv preprint.

- **Deposit large or complex data at well-established data centers.** If the data are either too large or too complex to be hosted by the journal, authors are encouraged to place their data in a trusted repository that issues Digital Object Identifiers (DOIs, more on this in §5.4). Adhere to the specific format requirements from the archives when contributing data.
- **Provide a complete list of metadata.** Metadata provide valuable information on various aspects of the data such as the creation, standards and quality of the data, and are often necessary to fully comprehend the data. For example, to visualize the position and orientation of the apertures on imagery, key metadata including aperture dimensions, center coordinates, and position angle are required.
- **Include a Data Availability Statement if required by the journal.** The statement provides a standardised format for the transparent reporting and description of the data underlying the paper.
- **Do not publish data sets at URLs lacking long-term support.** We strongly discourage the publication of URLs to personal web servers hosting data sets for which the author or institution has no means to maintain for many years after the publication of the associated journal article. This will greatly hinder future effort by researchers to retrieve and reuse the data.

The Common Archive Observation Model (CAOM²⁷) enables the storage of observational metadata from the complete set of telescopic data and searching through that metadata using a single interface. Authors are encouraged to provide as much information used by CAOM as possible when preparing metadata files. For image and spectral data specifically, authors are also recommended to consult the metadata requirements of the International Virtual Observatory Alliance (IVOA²⁸) that supports queries using IVOA’s Simple Image Access (SIA²⁹) protocol and Simple Spectral Access (SSA³⁰) protocol.

In Appendix B, we provide a partial list of well-reputed data repositories that support long-term storage

²⁵ The American Astronomical Society; <https://aas.org/>

²⁶ https://journals.aas.org/graphics-guide/#preparing_files

²⁷ <https://www.cadc-ccda.hia-ihp.nrc-cnrc.gc.ca/en/doc/caom/>

²⁸ <https://ivoa.net/>

²⁹ <http://www.ivoa.net/documents/SIA/>

³⁰ <https://www.ivoa.net/documents/SSA/>

and access to scientific catalogs, images, spectra, light curves, data cubes, radio visibility, probabilistic density functions and other large data files.

5. CITATIONS AND CREDITS

5.1. *Literature citations*

The AAS president in May/June 2009, Dr. John Huchra, wrote: “Authors have a strong tendency to under-attribute, that is not to properly cite both previous ideas and basic data. The phrases ‘data are available’ or ‘it is known that’ should never be used; someone had to work fairly hard to get that data or develop that idea and they deserve credit, even if they are your competitors. Also complicated is the use of master compilations, easy, but again not giving credit where credit is really due.”³¹

To properly cite data in an article, one should always:

- **Cite the original references.** For example, if the redshift presented is obtained from NED, use phrases such as “We adopted a heliocentric redshift of 1.234 (Smith et al. 2012)”, where “Smith et al. 2012” is listed correctly in your bibliography.
- **Use preferred citations by the authors.** Follow the instructions provided by the authors of the original papers, software etc. and use what the authors preferred for citations. For example, if 2MASS data are used in your analysis, the 2MASS web page³² requests that you cite the canonical paper by [Skrutskie et al. \(2006\)](#), instead of the Explanatory Supplement³³. A separate standard acknowledgment is also listed there to be included in the acknowledgments.
- **Provide full provenance of the data.** Ensure full reproducibility of the analysis performed in the paper by citing all data/source/software used: explicitly list the data identifiers provided by the data center in a table or in the text. For example, if 2MASS data is used via TOPCAT³⁴ accessing the VizieR table, then the source of the 2MASS data (“as downloaded with TOPCAT via Vizier”) should be stated, in addition to any preferred citations of the data itself. It is also recommended to

³¹ The President’s Column in the May/June 2009 AAS Newsletter by Dr. John Huchra; https://aas.org/archives/Newsletter/Newsletter.146.2009.05.May_June.pdf

³² <https://irsa.ipac.caltech.edu/Missions/2mass.html>

³³ <https://irsa.ipac.caltech.edu/data/2MASS/docs/releases/allsky/doc/explsup.html>

³⁴ <http://www.star.bris.ac.uk/~mbt/topcat/>

include the names of principal investigators who acquired the original data sets.

- **Include all references in the bibliography.** Make sure all appropriate references to papers, software and data products are included in a paper’s bibliography section, not just in footnotes. This will ensure proper attribution of citations to them. More details and examples on this can be found in the AAS Journal Reference Instructions³⁵.
- **Distinguish original data in your article and data taken from other work.** Use phrases such as “This work” to clearly identify original data in your article. It is important to archives, data services, and other authors that papers distinguish new information and measurements from those made by previous work.

5.2. *Facility credits*

Proper credit needs to be given to the facility or service used to obtain the data in an article. This may be hardware (telescopes and instruments) or on-line services (databases). Not only are the specifics essential to properly understand the data, the acknowledgement metric is also used as a basis for productivity by organizations maintaining telescopes, archives serving the data, and funding agencies for those facilities. We therefore recommend:

- **Explicitly indicate the facility involved.** Always describe the facilities or services used, and make sure the name is unique. Examples of possible confusion are given in Table 2.
- **Use standardized keywords when possible.** The AAS has created keyword tags³⁶ to be used with AASTeX `\facility` and `\facilities`. Many major astronomical archives, databases, and computational centers have been recently added to this list (e.g., CDS, Exoplanet Archive, IRSA, NED).
- **Include facility’s own statement if available.** Refer to the phrase that was in place at the time the facility was used.

³⁵ <https://journals.aas.org/references/>

³⁶ <https://journals.aas.org/authors/aastex/facility.html>

Table 2. Examples of ambiguous telescope/instrument names in literature

Name as published	Possible interpretation
ARO	Astronomical Research Observatory Arizona Radio Observatory Abbey Ridge Observatory Algonquin Radio Observatory
DDO	David Dunlap Observatory:0.15m David Dunlap Observatory:0.5m David Dunlap Observatory:0.6m David Dunlap Observatory:1.88m
EMIR	“Eight MIXer Receiver” on the IRAM 30m radio telescope “Espectrógrafo Multiobjeto Infra-Rojo” on the Gran Telescopio Canarias
OSIRIS	“OH-Suppressing Infra-Red Imaging Spectrograph” on the Keck I telescope “Ohio State Infrared Imager/Spectrograph” on the SOAR telescope “Optical System for Imaging and low-Intermediate-Resolution Integrated Spectroscopy” on the Gran Telescopio Canarias

5.3. Software credits

The increasing volume and complexity of the astronomical data require a lot of software processing in obtaining, calibrating, and analyzing the data and building the final product. Similar to acknowledging the facilities and services, we recommend:

- **List the software and version used in the production of the article.** Use the preferred citation if available. If not, include the name of the author(s), title of the program/source code, the code version and a URL link to the code publisher. This will ensure proper credit is given, and at the same time help with reproducibility.

The Astrophysics Source Code Library (ASCL³⁷) provides a list of common codes and software packages that are of interest to astronomers and astrophysicists, and their preferred citation methods.

5.4. Digital object identifiers

A digital object identifier (DOI³⁸) provides a persistent and unique identification of objects of any type, and is widely used to identify content related to published articles. Authors are encouraged to:

- **Use DOIs to cite related content if available.** This includes specific data sets, software, and ser-

vices used to produce results in the published articles. Archive these in persistent repositories and link them to the article through DOIs minted by the repositories. The DOI links should be included in the bibliography to ensure proper citation, and also be put where the data are discussed to make it easier for readers to locate and access the data.

Some resources for obtaining DOIs for specific data sets at the archives, as well as guidelines for using them in the journal articles, are provided in Appendix C. When DOIs are not available, authors can use the exact data set identifiers from the archives where the data were obtained. When archive data set identifiers cannot be obtained, authors are advised to give as much detailed criteria to identify the data as possible, e.g., list the start or stop times of every observation analyzed in the paper.

6. DATA CONTENT KEYWORDS

Traditional keywords used in journal articles do not capture information about the types of data presented in the article, for example, whether the article presents new position measurements (astrometry), photometric data, spectroscopic data, etc. This greatly limits the possibility of filtering literature searches based on the availability of these specific types of data. We suggest that authors:

- **Tag articles with relevant data content keywords from the Unified Astronomy The-**

³⁷ <https://ascl.net/>

³⁸ https://en.wikipedia.org/wiki/Digital_object_identifier#cite_note-iso-1

saurus (UAT³⁹). The UAT is adopted as a standard by the AAS journals⁴⁰ and the broader astronomical community including ADS. Hence we recommend that authors tag their articles with UAT keywords that best describe the types of data contained in the article.

7. SUMMARY

We hope the guidelines provided here will assist authors in preparing and publishing their data in a way that allows science claims to be clearly communicated, and readily understood and validated by readers. These best practices are intended to be used not only by authors during the preparation and submission stages of a publication, but also by referees, editors and publishers during the refereeing and editing stages before final publication. This will improve the quality of the published research record, expedite the integration of data into the databases with more efficiency and accuracy, and result in long-term preservation and reuse of valuable data. This will in turn enable more scientific discoveries that would otherwise not be possible or

practical, and increase citations for authors. A copy of this document and the checklist can be accessed at <https://ned.ipac.caltech.edu/uri/Docs::BPDP>. We expect that these best practices will evolve as new forms of data are published in the journals, and we welcome feedback and input from authors, publishers, archive users, and all interested parties.

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3. Adam Leary, Oxford University Press, UK
4. Greg J. Schwarz, American Astronomical Society, USA

APPENDIX

A. CHECKLIST OF RECOMMENDATIONS FOR PUBLISHING DATA

This checklist is a digest version of detailed information given in this article. It is intended to be a short reference for authors, referees, and science editors to consult in order to avoid various pit-falls that often impede the interpretation of data and metadata by readers, and parsing by software, and therefore also complicate and delay integration of the data into astronomical databases.

1. General rules (§2)
 - (a) Define all symbols, acronyms, and abbreviations at first use.
 - (b) Provide uncertainty and confidence level when reporting a new measurement.
 - (c) Present the appropriate number of significant figures for numerical measurements and uncertainties that match the precision of the measurements.
 - (d) Adopt commonly-used units whenever possible.
 - (e) Indicate preferred values if applicable.
2. Nomenclature (§2.1)
 - (a) Provide the complete name for each object. (§2.1.1)
 - (b) Include the “J” in names based on J2000 coordinates. (§2.1.1)
 - (c) Insert spacers between a catalog name and the identifiers within the catalog. (§2.1.1)
 - (d) Distinguish between part of an object and the object itself. (§2.1.1)

³⁹ <http://astrothesaurus.org/>

⁴⁰ <https://journals.aas.org/aas-journals-uat/>

- (e) Do not use the same name for different objects. (§2.1.1)
- (f) Always assign a name and verify the name is unique. (§2.1.2)
- (g) Keep the appropriate number of significant figures in coordinate-based names. (§2.1.2)
- (h) Use established names for known objects and check for the correct formatting. (§2.1.3)
- (i) Confirm the names and positions for cross-identifications. (§2.1.4)
- (j) Cross-match the same objects in different tables within the same article. (§2.1.4)

3. Astrometry (§2.2)

- (a) Provide the best available coordinates.
- (b) Specify the celestial reference system and/or frame.
- (c) Indicate the equinox and epoch of observation when necessary.
- (d) State the wavelength range from which astrometry is obtained.

4. Photometry (§2.3)

- (a) State the facility, telescope and instrument used.
- (b) Describe the method used to estimate photometry.
- (c) Use standard passband/filter identifiers.
- (d) Clarify the magnitude system.
- (e) Specify spectral transitions completely.

5. Time (§2.4)

- (a) Provide the time of observation and exposure time.
- (b) Favor full Julian Dates over abbreviated or offset Julian Dates.
- (c) Include phase timing measures along with reported periods when relevant.
- (d) State when observations from multiple missions are executed simultaneously.

6. Redshift/velocity (§2.5)

- (a) Define the method of redshift measurements (spectroscopic, photometric, etc.) and give references to the model/method.
- (b) Specify the reference frame of the redshift measurements (barycentric, heliocentric, galactocentric, etc.).
- (c) State whether a published redshift or recessional velocity is based on observed frequency or wavelength shifts (i.e., radio or optical convention).
- (d) Provide the wavelength range from which the redshift/velocity is obtained.
- (e) Indicate the quality of the measurement when possible.

7. Classifications (§2.6)

- (a) Utilize established classifications as available.
- (b) Define new classifications clearly.

8. Orbital parameters (§2.7)

- (a) Avoid using “longitude of periapsis” in place of “argument of periapsis”.
- (b) Be explicit about which body’s orbit a longitude or argument of periapsis refers to (e.g., planet or host star).
- (c) Include time of periapsis as appropriate.

9. Tables (§3.1)

- (a) Provide a clear title and unambiguous labels for columns.
- (b) Explain the contents of each column, including symbols and flags.
- (c) Use the same explicitly defined null for missing values throughout.
- (d) Prepare standard ReadMe files for machine-readable tables.

10. Figures (§3.2)

- (a) Provide clear caption, legend and axis labels for each figure.
- (b) Design the graphics to be accessible.
- (c) Make public data files used to create the figures.

11. Data archiving and access (§4)

- (a) Append small data sets as part of the publication.
- (b) Deposit large or complex data at a long-term archive most appropriate for your data. Adhere to the specific format requirements from the archives.
- (c) Provide a complete list of metadata.
- (d) Include a Data Availability Statement if required by the journal.
- (e) Do not publish data sets at URLs lacking long-term support.

12. Literature citations (§5.1)

- (a) Cite the original references.
- (b) Use preferred citations by the authors.
- (c) Provide full provenance of the data. Credit the originator of archival data, including the Principal Investigator.
- (d) Include all references in the bibliography section.
- (e) Distinguish original data in your article and data taken from other work.

13. Facility credits (§5.2)

- (a) Indicate the facilities involved, such as telescopes, instruments, and databases.
- (b) Use standard keywords when possible.
- (c) Include facility's own statement if available.

14. Software credits (§5.3)

- (a) List the software and version used in the production of the article.

15. Digital object identifiers (§5.4)

- (a) Use DOIs to cite data sets, software and services if available.

16. Data content keywords (§6)

- (a) Tag articles with relevant data content keywords from the UAT.

B. DATA REPOSITORIES

We list here some data repositories (both special-purpose and general-purpose ones) that are available to support long-term storage and access to scientific catalogs, images, spectra, light curves, code, and other large data files used to produce the figures and results that appear in journal articles. This is not a complete list. Authors are encouraged to explore and choose a well-established repository that is most appropriate for your data. At the time your data are contributed, please acquire a DOI or other persistent URL suitable for publication in the journal article.

Astronomy data repositories:

1. ExoFOP; <https://exofop.ipac.caltech.edu/>; online environment for the community to upload and share observations, data, files, and notes on exoplanet candidates.
2. HEASARC; <https://heasarc.gsfc.nasa.gov/>; astrophysics catalogs, images, spectra, time series.
3. IRSA; <https://irsa.ipac.caltech.edu/frontpage/>; astrophysics catalogs, images, spectra, time series.
4. KOA; <https://koa.ipac.caltech.edu/>; astrophysics catalogs, images, spectra, time series; raw and contributed science products.
5. MAST; <https://archive.stsci.edu/>; astrophysics catalogs, images, spectra, time series, publication records, etc.
6. NASA Exoplanet Archive; <https://exoplanetarchive.ipac.caltech.edu/>; data and derived astrophysical parameters for exoplanets and exoplanet candidates.
7. VizieR; <https://vizier.unistra.fr/>; astrophysics catalogs, images, spectra.

General-purpose data repositories:

1. Code Ocean; <https://codeocean.com/>; all research data and code.
2. DataHub; <https://datahub.io/>; all research data and metadata.
3. Figshare; <https://figshare.com/>; all research data and metadata.
4. Harvard Dataverse; <https://dataverse.harvard.edu/>; all research data and metadata.
5. Mendeley Data; <https://data.mendeley.com/>; all research data and metadata.
6. Open Science Framework; <https://osf.io/>; all research data and metadata.
7. ScienceDB; <http://www.scidb.cn/en/>; all research data and metadata.
8. Zenodo; <https://zenodo.org/>; all research data and metadata.

C. LIST OF DOIS

We present here a list of DOIs that journals and archives prefer authors to use.

Resources for publishing DOIs in astrophysics journals:

1. AAS Journals guidelines for citing 3rd party data repositories and software; <https://journals.aas.org/aastexguide/#softwareandthirdparty>.
2. MNRAS data policy on availability and citation of data; https://academic.oup.com/mnras/pages/General_Instructions#2.9%20Data%20Policy.
3. Oxford University Press guidelines for selecting a repository that will issue a DOI; https://academic.oup.com/journals/pages/authors/preparing_your_manuscript/research-data-policy#choosing.

Resources for obtaining DOIs from astrophysics archives:

1. CDS; CDS creates DOIs for catalogs when they are ingested in VizieR. This DOI is for the digital object of the catalog in VizieR and is complementary to the DOI of the publication.

2. Chandra Data Archive; https://cxc.cfa.harvard.edu/cda/cda_doi.html.
3. Exoplanet Follow-up Observing Program (ExoFOP); <https://www.ipac.caltech.edu/doi/exofop>.
4. IPAC Archives; <https://www.ipac.caltech.edu/doi/>.
5. IRSA; <https://www.ipac.caltech.edu/doi/irsa>.
6. KOA; <https://www.ipac.caltech.edu/doi/koa>.
7. MAST; <https://archive.stsci.edu/access-mast-data/digital-object-identifier-doi>.
8. NASA Exoplanet Archive; <https://www.ipac.caltech.edu/doi/exoplanet-archive>.
9. NED; <https://www.ipac.caltech.edu/doi/ned>.

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