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Using 100-m Radio Telescope to Detect the 21-cm Signal During the Epoch of Reionization

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ABSTRACT

Despite extensive efforts, direct observational constraints on the epoch of reionization (EoR) remain scarce, and our understanding of this pivotal cosmic era is correspondingly limited. The redshifted 21-cm line of neutral hydrogen constitutes the most direct probe of reionization, yet the Square Kilometre Array (SKA) is still under construction, thereby impeding progress in EoR studies. Here, we demonstrate that 100 m-class single-dish radio telescopes can be used to detect the 21-cm signal from the EoR and to impose stringent bounds on reionization model parameters. We employ the semi-numerical code 21cmFAST to generate three-dimensional light-cone simulations of the 21 cm brightness-temperature field, and we base our observational forecasts on these mock data. Given the angular resolution limited by the 100-m aperture, our analysis focuses on the one-dimensional (line-of-sight, LoS) power spectra of the history-mean-subtracted 21 cm signal. We find that, with a total integration time of 100 h, a cumulative signal-to-noise ratio (SNR) in excess of 5σ is achievable, rising to above 19σ for 1000 h of observations. These results indicate that the three 100 m-class radio telescopes currently under construction in China possess the capability to deliver the first statistically robust measurement of the LoS EoR 21-cm power spectrum well before the SKA becomes available.

Keywords: Galaxies (573) — Cosmology (343) — High Energy astrophysics (739) — Interstellar medium (847) — Stellar astronomy (1583) — Solar physics (1476)

1. INTRODUCTION

Cosmology is a field driven by observations and data. For very high redshifts, the CMB observation provides the knowledge about the primordial initial conditions for the evolution of the late universe. For low redshifts (z $O(1)$), the statistical properties of the large scale structure of the universe could be obtained from large galaxy surveys. However, the intermediate redshift range, from about $z = 5$ to $z = 30$, covering the cosmic dawn and the Epoch of Reionization (EoR), is still lack of direct observations. Indirect observations, such as the optical depth of the CMB photons, only provide a loose constraints of the reionization redshift with rough reionization history models like "TANH" model. The direct tracer of the EoR and cosmic dawn is just the 21-cm line signal, which is the hyperfine transition line of the ground state of the neutral hydrogen atom. Although the astrophysical information of the 21-cm signal is rich, the signal itself is very weak, and the foreground contamination is about 4-5 orders of magnitude larger than the signal, making the noise suppression and foreground removal the main challenges of the 21-cm signal detection.

The 21-cm signal observations can be roughly diveded into two categories: global signal and fluctuation signal. The global signal observations do not care about the temperature differences between different sky directions, only focusing on the average brightness temperature varing with redshifts, or frequencies, so the detector will be relatively smaller than the fluctuation signal observations. The most famous detection claim of the 21-cm signal in the cosmic dawn is from the EDGES experiment, which reported a strong absorption feature around $z \sim 17$ which is over 500mK, more than twice the maximum expected value with the known physical process considered. This unexpected strong absorption feature is still not confirmed by other experiments, and SARAS 3 group reported a null detection of the EDGES' signal with only a noise signal with rms 213mK. Though the experimental setting of global signal detection is relatively simple, the strong foreground makes the result highly controversial. On the other hand, the fluctuation signal detection offers another view to study the 21-cm signal structure and astrophysics. The ionizing photons from stars and AGN are highly inhomogeneously distributed, making the 21-cm brightness temperature distribute with bubble-like and island-like structures in early and late EoR respectively. Based on summary statistics like power spectrum, we can extract the underlying astrophysical information and improve our understanding of the ionizing models. Currently, the SKA is the most promising experiment to detect the 21-cm fluctuation signal, but it is still under construction, and scientific observation will be available after 2029. Except SKA, HERA is the most sensitive experiment for the 21-cm power spectrum. However, it has ended the data collection due to finacial problems and its data is not publicly available yet.

Considering the difficulties in the mainstream global signal and fluctuation signal detection both, we propose here a new method to observe and analyze the 21-cm signal in EoR. Assuming that we have a large single dish radio telescope, with a diameter around 100m, we can point it to different foreground low directions in the sky with the tracking model and collect the radio signals from these directions with integration time around 10 hours each. After removing the foreground and subtracting the average history evolution along the line of sight of these directions, we can then obtrain the average spectrum of these line of sights. In order to foreacast the expected signal and the astrophysical information contained in the signal, we apply the semi-numerical simulation code 21cmFAST to generate the 21-cm brightness temperature light cone fields, and then mock the observation line of sight sampling process. For the forecast of the constraining ability of the astrophysical parameters, we vary the paramters ζ (ionizing efficiency) and $T_{\rm vir}$ (minimal virial temperature of halos which can produce ionizing photons) in the brightness temperature simulation. By comparing the average spectra of different parameter combinations, we can then estimate the constraining ability of the data collected from 100-m single dish radio telescope.

The rest of this paper is organized as follows. In section 2, we introduce the simulation setting details of our runs of 21cmFAST and the mock observation process. In section 3, we show the results of the average line of sight spectra and the constraing ability of the astrophysical parameter sets. Finally, we summerize our work and give a discussion about the difficulties of this observation mode/method in section 4.

2. METHODOLOGY

2.1. *Simulations and Sample Selection*

As a simplest estimation for the resolution for the single dish telescope, we use the formula:

$$\theta = \frac{\lambda_z}{D}, \tag{1}$$

in which θ is the angular resolution, λ_z is the wavelength of the redshifted observed signal, and D is the effective diameter of the radiotelescope. Using Hubble constant $H_0 = 67.4$ km s^{-1} Mpc^{-1}, $\Omega_m = 0.3$, and $\Omega_\Lambda = 0.7$, we can calculate the corresponding angular resolution for our observations, which is shown in table 1.

Table 1. Redshifted 21-cm line frequencies, angular resolutions and comoving perpendicular resolutions of the single dish telescopes at different redshifts.

D/m	$z=5$			$z=8$			$z=12$		
	f/MHz	θ	d/Mpc	f/MHz	θ	d/Mpc	f/MHz	θ	d/Mpc
300	236	0.242°	34.1	158	0.363°	58.9	109	0.524°	93.3
100		0.726°	102		1.08°	177		1.57°	280

3. RESULTS

This is the results section.

4. SUMMARY

This is the summary section.

5. A SHORT HISTORY OF AASTEX

LaTeX [2] is a document markup language that is particularly well suited for the publication of mathematical and scientific articles (L. Lamport 1994). LaTeX was written in 1985 by Leslie Lamport who based it on the TEX typesetting language which itself was created by Donald E. Knuth in 1978. In 1988 a suite of LaTeX macros were developed to investigate electronic submission and publication of AAS Journal articles (R. J. Hanisch & C. D. Biemesderfer 1989). Shortly afterwards, Chris Biemesdefer merged these macros and more into a LaTeX 2.08 style file called AASTEX. These early AASTEX versions introduced many common commands and practices that authors take for granted today. Substantial revisions were made by Lee Brotzman and Pierre Landau when the package was updated to v4.0. AASTeX v5.0, written in 1995 by Arthur Ogawa, upgraded to LaTeX 2e which uses the document class in lieu of a style file. Other improvements to version 5 included hypertext support, landscape deluxetables and improved figure support to facilitate electronic submission. AASTEX v5.2 was released in 2005 and introduced additional graphics support plus new mark up to identifier astronomical objects, datasets and facilities.

In 1996 Maxim Markevitch modified the AAS preprint style file, aaspp4.sty, to closely emulate the very tight, two column style of a typeset Astrophysical Journal article. The result was emulateapj.sty. A year later Alexey Vikhlinin took over development and maintenance[3]. In 2001 he converted emulateapj into a class file in LaTeX 2e and in 2003 Vikhlinin completely rewrote emulateapj based on the APS Journal's REVTEX class.

During this time emulateapj gained growing acceptance in the astronomical community as it filled an author need to obtain an approximate number of manuscript pages prior to submission for cost and length estimates. The tighter typeset also had the added advantage of saving paper when printing hard copies.

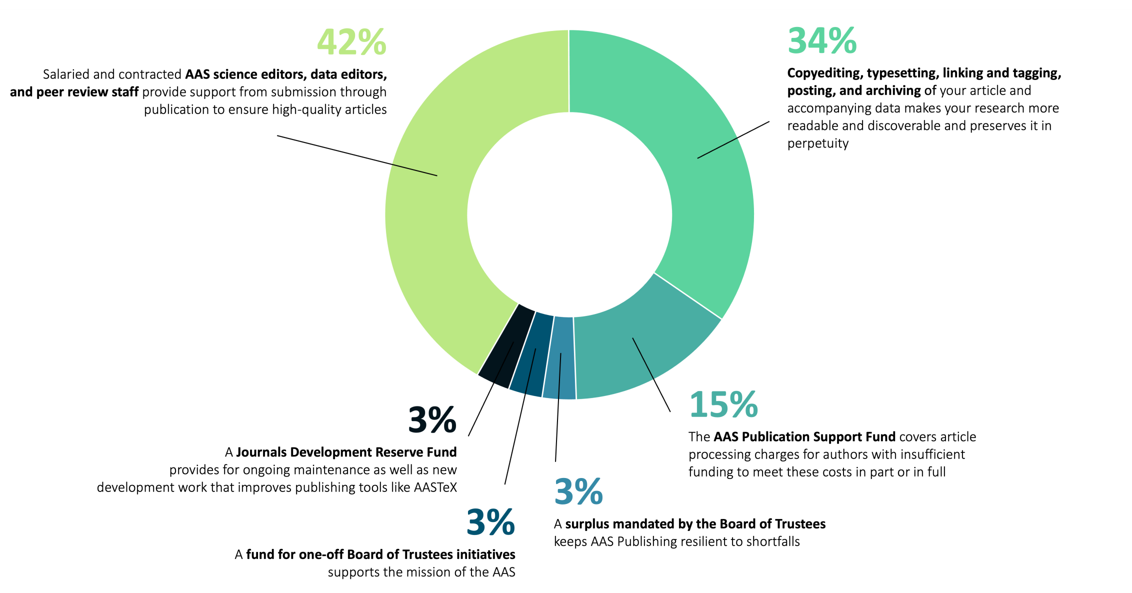

Figure 1. The AAS journals are operated as a nonprofit venture, and author charges fairly recapture costs for the services provided in the publishing process. The chart above breaks down the services that author charges go toward. The AAS Journals' Business Model is outlined in a 2023 post.

Even though author publication charges were no longer based on print pages [4] the emulateapj class file proved to be extremely popular with AAS Journal authors. An analysis of submitted LaTeX manuscripts in 2015 revealed that $\sim$30% either called emulateapj or had a commented emulateapj classfile call indicating it was used at some stage of the manuscript construction. Clearly authors wanted to have access to a tightly typeset version of the article when editing with co-authors and for preprint submissions.

[2] http://www.latex-project.org/

[3] https://hea-www.harvard.edu/~alexey/emulateapj/

[4] see Section B in the Appendix for more details about how current article costs are calculated. Figure 1 shows how author publication charges are currently spent.

When planning the next AASTEX release the popularity of emulateapj played an important roll in the decision to drop the old base code and adopt and modify emulateapj for AASTEX v6.+. Those changes brought AASTEX inline with what the majority of authors were already using while still delivering new and improved features. AASTEX v6.0 through v6.31 were developted by Amy Hendrickson[5]. The release dates for the AASTEX6 versions were January 2016 (v6.0), October 2016 (v6.1), January 2018 (v6.2), June 2019 (v6.3), and March 2020 (v6.3.1), respectively.

AASTEXś reliance on REVTeX, specifically v4-1, proved to be problematic when it was superseded in in January 2019. Rather than continue with REVTeX v4-2 as the base package of AASTEX, Aptara[6] was hired to rewrite AASTEXfrom scratch while keeping the core functionality in early 2024. This new version, v7.0, was released in January 2025. The first bug fix was release in May 2025 as v7.0.1. Users of v6.3.1 will have little difficulty migrating to this new version with the core difference being that an email address is required for each author in v7+.

The rest of this article provides information and examples on how to create your own AAS Journal manuscript with v7+. Special emphasis is placed on how to use the full potential of AASTEX. Note that some of the examples are commented out in this latex manuscript. The next section describes the different manuscript styles available. Section 7 describes table and figure placement. Specific examples of different tables are provided, Section 7.1. Section 8 discusses how to properly highlight text added during revisions. The last section, 9, shows how to recognize software and external data as first class references in the manuscript bibliography. An appendix is included for additional information readers might find useful. More documentation is embedded in the comments of this LaTEX file and in the online documentation at http://journals.aas.org/authors/aastex.html.

6. MANUSCRIPT STYLES

The default style in AASTEX v7+ is a tight single column style, e.g. 10 point font, single spaced. The single column style is very useful for articles with wide equations. It is also the easiest style to work with since figures and tables, see Section 7, will span the entire page, reducing the need for address float sizing.

To invoke a two column style similar to what is produced in the published PDF copy use:

`\documentclass[twocolumn]{aastex7}`.

Note that in the two column style figures and tables will only span one column unless specifically ordered across both with the "*" flag, e.g.

`\begin{figure*}` ... `\end{figure*}`,
`\begin{table*}` ... `\end{table*}`, and
`\begin{deluxetable*}` ... `\end{deluxetable*}`.

This option is ignored in the `onecolumn` style.

All authors should have the `linenumbers` style included so that the compiled PDF has each row numbered in the left margin. Line numbering is mandatory as it helps reviewers quickly identify locations in the text.

The `anonymous` option will prevent the author and affiliations from being shown in the compiled pdf copy. This option allows the author to keep this critical information in the latex file but prevent the reviewer from seeing it during peer review if dual anonymous review (DAR) is requested. Likewise, acknowledgments and author contributions can also be hidden if placed in the `\begin{acknowledgments}` ... `\end{acknowledgments}` and `\begin{contribution}` ... `\end{contribution}` environments. The use of this option is highly recommended for PSJ submissions. Advice for anonymizing your manuscript for DAR is provided at https://journals.aas.org/manuscript-preparation/#dar.

Another reason to use the `\begin{acknowledgments}` ... `\end{acknowledgments}` and `\begin{contribution}` ... `\end{contribution}` environments is that the word counter in our peer review system will **not** count the contents of these environments. If authors put acknowledgments and contribution text in other locations, these words will be counted and authors may be overcharged on their author publication charges.

Multiple style options are allowed, e.g.

[5] https://www.texnology.com/about.htm
[6] https://www.aptaracorp.com

\documentclass[linenumbers,trackchanges,anonymous]{aastex7}.

7. FLOATS

Floats are non-text items that generally cannot be split over a page. They also have captions and can be numbered for reference. Primarily these are figures and tables but authors can define their own. LaTeX tries to place a float where indicated in the manuscript but will move it later if there is not enough room at that location, hence the term "float".

Authors are encouraged to embed their tables and figures within the text as they are mentioned. Editors and the vast majority of referees find it much easier to read a manuscript with embedded figures and tables.

Depending on the number of floats and the particular amount of text and equations present in a manuscript the ultimate location of any specific float can be hard to predict prior to compilation. It is recommended that authors **not** spend significant time trying to get float placement perfect for peer review. The AAS Journal's publisher has sophisticated typesetting software that will produce the optimal layout during production.

Note that authors of Research Notes are only allowed one float, either one table or one figure.

For authors that do want to take the time to optimize the locations of their floats there are some techniques that can be used. The simplest solution is to place a float earlier in the text to get the position right but this option will break down if the manuscript is altered. A better method is to force LaTeX to place a float in a general area with the use of the optional `[placement specifier]` parameter for figures and tables. This parameter goes after `\begin{figure}`, `\begin{table}`, and `\begin{deluxetable}`. The main arguments the specifier takes are "h", "t", "b", and "!". These tell LaTeX to place the float here (or as close as possible to this location as possible), at the top of the page, and at the bottom of the page. The last argument, "!", tells LaTeX to override its internal method of calculating the float position. A sequence of rules can be created by using multiple arguments. For example, `\begin{figure}[htb!]` tells LaTeX to try the current location first, then the top of the page and finally the bottom of the page without regard to what it thinks the proper position should be. Many of the tables and figures in this article use a placement specifier to set their positions.

Note that the LaTeX `tabular` environment is not a float. Only when a `tabular` is surrounded by `\begin{table}` ... `\end{table}` is it a true float and the rules and suggestions above apply.

In AASTeX all deluxetables are float tables and thus if they are longer than a page will spill off the bottom. Long deluxetables should begin with the `\startlongtable` command. This initiates a longtable environment. Authors might have to use `\clearpage` to isolate a long table or optimally place it within the surrounding text.

7.1. *Tables*

Tables can be constructed with LaTeX's standard table environment or the AASTeX's deluxetable environment. The deluxetable construct handles long tables better but has a larger overhead due to the greater amount of defined mark up used to set up and manipulate the table structure. The choice of which to use is up to the author. Examples of both environments are used in this manuscript.

Tables longer than 200 data lines and complex tables should only have a short example table with the full data set available in the machine readable format. The machine readable table will be available in the HTML version of the article with just a short example in the PDF. Authors are required to indicate in the table comments that the data is in machine readable format in the full article. Authors are encouraged to create their own machine readable tables using the online tool at http://authortools.aas.org/MRT/upload.html.

AASTeX v6 introduced five new table features that were designed to make table construction easier and the resulting display better for AAS Journal authors. The items are:

1. Declaring math mode in specific columns,
2. Column decimal alignment,
3. Automatic column header numbering,
4. Hiding columns, and
5. Splitting wide tables into two or three parts.

Table 2. Measurements of Emission Lines: two breaks

Model	Component	Shift	FWHM	Flux									
		(km s^{-1})	(km s^{-1})	(10^{-17} erg s^{-1} cm^{-2})									
				Lyα	N V	Si IV	C IV	Mg II	Hγ	Hβ	Hα	He I	Paγ
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)
	BELs	-97.13	9117±38	1033±33	< 35	< 166	637±31	1951±26	991±30	3502±42	20285±80	2025±116	1289±107
Model 1	IELs	-4049.123	1974±22	2495±30	< 42	< 109	995±186	83±30	75±23	130±25	357±94	194±64	36±23
	NELs	...	641±4	449±23	< 6	< 9	–	275±18	150±11	313±12	958±43	318±34	151±17
	BELs	-85	8991±41	988±29	< 24	< 173	623±28	1945±29	989±27	3498±37	20288±73	2047±143	1376±167
Model 2	IELs	-51000	2025±26	2494±32	< 37	< 124	1005±190	72±28	72±21	113±18	271±85	205±72	34±21
	NELs	52	637±10	477±17	< 4	< 8	–	278±17	153±10	317±15	969±40	325±37	147±22

Note—This is an example of how to split a deluxetable. You can split any table with this command into two or three parts. The location of the split is given by the author based on the placement of the "B" indicators in the column identifier preamble. For more information please look at the new AASTEX instructions.

Full details on how to create each of these special table types are given in the guidelines at http://journals.aas.org/authors/aastex.html.

7.1.1. *Extremely wide tables*

Since the AAS Journals are now all electronic with no print version there is no reason why tables can not be as wide as authors need them to be. For wide tables, the full table will almost always be available in machine readable format with just an example in the article but how is an example created for a wide table?

There are two ways to create examples for wide tabular data sets. The first is to to break a table into two or three components so that it flows down a page by invoking a new table type, splittabular or splitdeluxetable. Within these tables a new "B" column separator is introduced. Much like the vertical bar option, "|", that produces a vertical table lines the new "B" separator indicates where to Break a table. Up to two "B"s may be included.

Table 1 shows how to split a wide deluxetable into three parts with the `\splitdeluxetable` command. The `\colnumbers` option is on to show how the automatic column numbering carries through the second table component.

The second way is to create a "descriptive" table instead. This type of table only provides information about the columns rather than the data itself. Table 2 shows an example of this type of table using the same columns as in

Table 3. Descriptive version of the "Measurements of Emission Lines" table

Number	Units	Label	Explanation
1	—	Model	Model identifier
2	—	Component	Component identifier
3	km s^{-1}	Shift	Line shift
4	km s^{-1}	FWHM	Line Full-Width at Half-Maximum
5	10^{-17} erg s^{-1} cm^{-2}	Lyα	Lyα line flux
6	10^{-17} erg s^{-1} cm^{-2}	N V	N V line flux
7	10^{-17} erg s^{-1} cm^{-2}	Si IV	Si IV line flux
8	10^{-17} erg s^{-1} cm^{-2}	C IV	C IV line flux
9	10^{-17} erg s^{-1} cm^{-2}	Mg II	Mg II line flux
10	10^{-17} erg s^{-1} cm^{-2}	Hγ	Hγ line flux
11	10^{-17} erg s^{-1} cm^{-2}	Hβ	Hβ line flux
12	10^{-17} erg s^{-1} cm^{-2}	Hα	Hα line flux
13	10^{-17} erg s^{-1} cm^{-2}	He I	He I line flux
14	10^{-17} erg s^{-1} cm^{-2}	Paγ	Paγ line flux

Note—Table 2 is published in its entirety in the electronic edition of the *Astrophysical Journal*. A portion is shown here for guidance regarding its form and content. The `\digitalasset` command highlights the Table title to visually indicate to the reader that there is data associated with this table.

Table 1. Since these types of tables always have a machine readable component, this table uses the `\digitalasset` command to highlight this fact.

7.2. *Figures*

Authors can include a wide number of different graphics with their articles. These range from general figures all authors are familiar with to new enhanced graphics that can only be fully experienced in HTML. The later include figure sets, animations and interactive figures. All enhanced graphics require a static two dimensional representation in the manuscript to serve as the example for the reader. All figures should include detailed and descriptive captions. These captions are absolutely critical for readers for whom the enhanced figure is inaccessible either due to a disability or offline access. This portion of the article provides examples for setting up all these types in with the latest version of AASTeX.

7.3. *General figures*

AASTeX has a `\plotone` command to display a figure consisting of one figure file. Figure 1 is an example which shows how AAS Publishing spends author publication charges. For a general figure consisting of two figure files the `\plottwo` command can be used to position the two image files side by side.

Both `\plotone` and `\plottwo` take a `\caption` and an optional `\figurenum` command to specify the figure number[7]. Each is based on the `graphicx` package command, `\includegraphics`. Authors are welcome to use `\includegraphics` along with its optional arguments that control the height, width, scale, and position angle of a file within the figure. More information on the full usage of `\includegraphics` can be found at https://en.wikibooks.org/wiki/LaTeX/Importing_Graphics#Including_graphics.

[7] It is better to not use `\figurenum` and let LaTeX auto-increment all the figures. If you do use this command you need to mark all of them accordingly.

7.4. *Enhanced graphics*

Enhanced graphics have an example figure to serve as an example for the reader and the full graphical item available in the published HTML article. This includes Figure sets, animations, and interactive figures. The Astronomy Image Explorer (http://www.astroexplorer.org/) provides access to all the figures published in the AAS Journals since they offered an electronic version which was in the mid 1990s. You can filter image searches by specific terms, year, journal, or type. The type filter is particularly useful for finding all published enhanced graphics. As of August 2024 there are over 5600 videos, 2200 figure sets, and 200 interactive figures. The next sections describe how to include these types of graphics in your own manuscripts.

8. REVISION TRACKING AND COLOR HIGHLIGHTING

The `\added{<text>}` command should be used to highlight new text in bold for revised manuscripts. To activate this command, the `trackchanges` option must be used in the `\documentclass` call. When compiled this will produce the marked text in bold font. Take out the `trackchanges` option if you want the bold to disappear.

This text was specifically added to feature this reborn functionality. Notice how the bold goes away when you remove the 'trackfeatures' option.

9. SOFTWARE AND THIRD PARTY DATA REPOSITORY CITATIONS

The AAS Journals would like to encourage authors to change software and third party data repository references from the current standard of a footnote to a first class citation in the bibliography. As a bibliographic citation these important references will be more easily captured and credit will be given to the appropriate people.

The first step to making this happen is to have the data or software in a long term repository that has made these items available via a persistent identifier like a Digital Object Identifier (DOI). A list of repositories that satisfy this criteria plus each one's pros and cons are given at https://github.com/AASJournals/Tutorials/tree/master/Repositories.

In the bibliography the format for data or code follows this format:

author year, title, version, publisher, prefix:identifier

L. Corrales (2015) provides a example of how the citation in the article references the external code at https://doi.org/10.5281/zenodo.15991. Unfortunately, bibtex does not have specific bibtex entries for these types of references so the "@misc" type should be used. The Repository tutorial explains how to code the "@misc" type correctly. The most recent .bst file, aasjournalv7.bst, will output bibtex "@misc" type properly.

Authors can also use the website https://www.doi2bib.org/ to create a BIBTeX entry for any DOI. Please check the output from this site carefully as its output is only as good as the DOI metadata. Some DOI creators do not provide enough metadata to construct an adequate citation.

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AUTHOR CONTRIBUTIONS

All authors contributed equally to the Terra Mater collaboration.

Facilities: HST(STIS), Swift(XRT and UVOT), AAVSO, CTIO:1.3m, CTIO:1.5m, CXO

Software: astropy (Astropy Collaboration et al. 2013, 2018, 2022), Cloudy (G. J. Ferland et al. 2013), Source Extractor (E. Bertin & S. Arnouts 1996)

APPENDIX

A. APPENDIX INFORMATION

Appendices can be broken into separate sections just like in the main text. The only difference is that each appendix section is indexed by a letter (A, B, C, etc.) instead of a number. Likewise numbered equations have the section letter appended. Here is an equation as an example.

$$I = \frac{1}{1 + d_1^{P(1+d_2)}} \tag{A1}$$

Appendix tables and figures should not be numbered like equations. Instead they should continue the sequence from the main article body.

B. AUTHOR PUBLICATION CHARGES

In April 2011 the traditional way of calculating author charges based on the number of printed pages was changed. The reason for the change was due to a recognition of the growing number of article items that could not be represented in print. Now author charges are determined by a number of digital "quanta". A single quantum is defined as 350 words, one figure, one table, and one digital asset. For the latter this includes machine readable tables, data behind a figure, figure sets, animations, and interactive figures. The current cost for the different quanta types is available at https://journals.aas.org/article-charges-and-copyright/#author_publication_charges. Authors may use the ApJL length calculator to get a `rough` estimate of the number of word and float quanta in their manuscript. The calculator is located at https://authortools.aas.org/ApJL/betacountwords.html.

C. ROTATING TABLES

To place a single page table in a landscape mode start the table portion with `\begin{rotatetable}` and end with `\end{rotatetable}`.

Tables that exceed a print page take a slightly different environment since both rotation and long table printing are required. In these cases start with `\begin{longrotatetable}` and end with `\end{longrotatetable}`. The `\movetabledown` command can be used to help center extremely wide, landscape tables. The command `\movetabledown=1in` will move any rotated table down 1 inch.

A handy "cheat sheet" that provides the necessary LaTeX to produce 17 different types of tables is available at http://journals.aas.org/authors/aastex/aasguide.html#table_cheat_sheet.

D. USING CHINESE, JAPANESE, AND KOREAN CHARACTERS

Authors have the option to include names in Chinese, Japanese, or Korean (CJK) characters in addition to the English name. The names will be displayed in parentheses after the English name. The way to do this in AASTeX is to use the CJK package available at https://ctan.org/pkg/cjk?lang=en. Further details on how to implement this and solutions for common problems, please go to https://journals.aas.org/nonroman/.

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