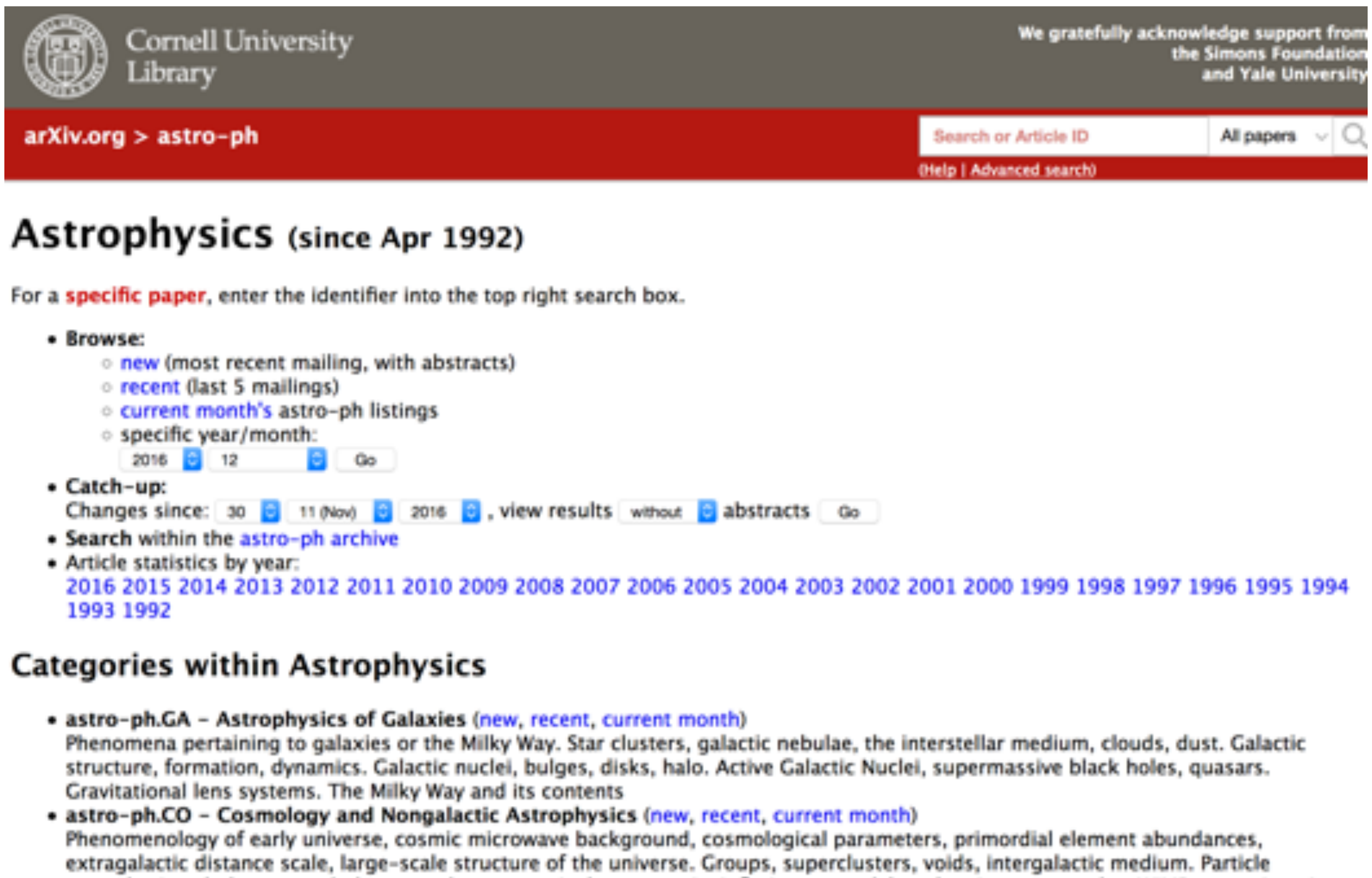
Readings for Lecture

From Gallaway “*An Introduction to Observational Astrophysics*”:

PS#9 is posted in full. Due Dec 20th.   Reading Week hours posted.

Astronomy Pro-Tips

Most astronomy papers are posted on astro-ph.
I scan submissions to this server each day and read one/two papers per week.



https://arxiv.org/archive/astro-ph/Astrophysics

Astronomy Pro-Tips

To search for papers on a specific topic, I use the Astrophysical Data System (ADS)


SAO/NASA ADS Astronomy Query Form for Tue Nov 19 18:29:05 2013

Sitemap What's New Feedback Basic Search Preferences FAQ HELP

Check out ADS Labs !

Send Query | Return Query Form | Store Default Form | Clear

Databases to query: Astronomy Physics arXiv e-prints

Authors: (Last, First M, one per line) SIMBAD NED ADS Objects

Exact name matching Object name/position search

Require author for selection Require object for selection

(OR AND simple logic) (Combine with: OR AND)

Publication Date between (MM) (YYYY) and (MM) (YYYY)

Enter Title Words Require title for selection

(Combine with: OR AND simple logic boolean logic)

Enter Abstract Words/Keywords Require text for selection

(Combine with: OR AND simple logic boolean logic)

Return 200 items starting with number 1

ADSLabs Full Integrated Search: Search within articles

myADS: Personalized notification service

To search for a specific first author
^Geha


SORTING

Sort by score
Sort by normalized score
Sort by citation count
Sort by normalized citation count
Sort by first author name
Sort by number of authors
Sort by date (most recent first)
Sort by date (oldest first)
Sort by entry date
Sort by page (ToC sort)

To search for highly cited papers, sort by citation count

http://adsabs.harvard.edu/abstract_service.html

Astronomy Pro-Tips: Introduction to LaTeX

LaTeX is the primary way to create documents in the physical sciences.

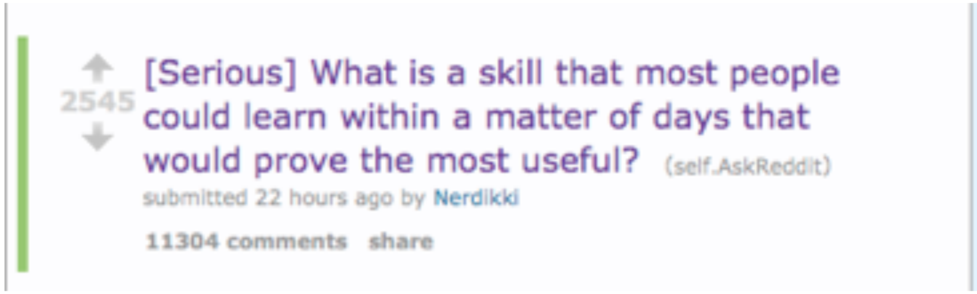
LaTeX is a system for creating documents. Instead of editing your document in a graphical way (e.g., MS Word or StarOffice), write a text file in an text editor, and process it with LaTeX, eventually creating a PostScript or PDF file.

Advantages of LaTeX over MS WORD or other word processing programs:

-- Its free!
-- Much easier to include math symbols and equations
-- Used by most science fields
-- Handles the bibliography intelligently

Introduction to LaTeX

Seen on Reddit:

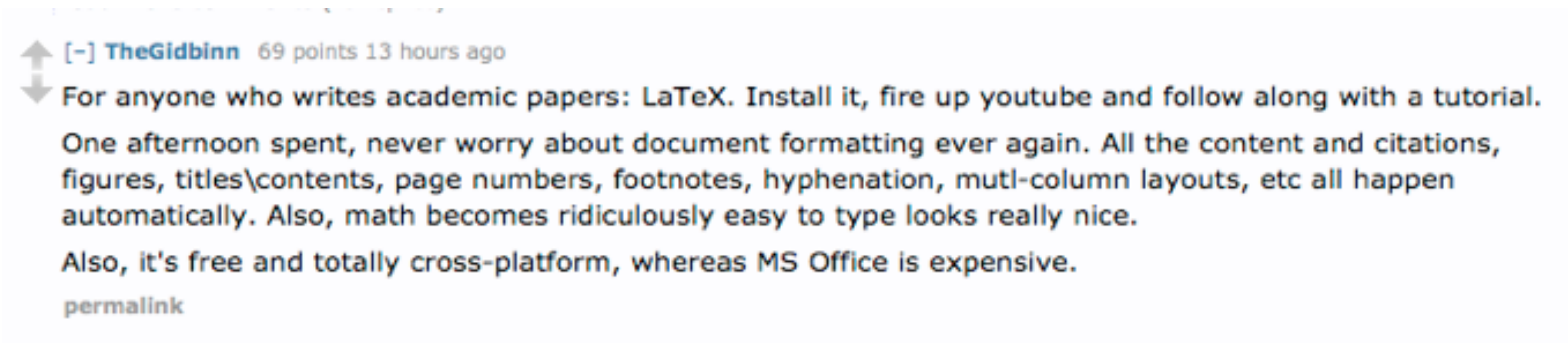


2545

[Serious] What is a skill that most people could learn within a matter of days that would prove the most useful? (self.AskReddit)

submitted 22 hours ago by Nerdikki

11304 comments share



[–] TheGidbinn 69 points 13 hours ago

For anyone who writes academic papers: LaTeX. Install it, fire up youtube and follow along with a tutorial.

One afternoon spent, never worry about document formatting ever again. All the content and citations, figures, titles\contents, page numbers, footnotes, hyphenation, mutl-column layouts, etc all happen automatically. Also, math becomes ridiculously easy to type looks really nice.

Also, it's free and totally cross-platform, whereas MS Office is expensive.

permalink

Introduction to LaTeX

```
% ABSTRACT
%
% Give a general abstract of the scientific justification appropriate
% for a non-specialist.  Write between the \begin{abstract} and
% \end{abstract} lines.  Limit yourself to approximately 175 words.
% Abstracts of accepted proposals will be made publicly available.

% DO NOT remove the \begin{abstract} and \end{abstract} lines.

\begin{abstract}
The Milky Way (MW) galaxy is host to two dozen dwarf galaxy
  satellites.  The brightest of these satellites and their properties
  do not fully agree with predictions from galaxy formation models.
  While it is possible that model predictions are incorrect, it is
  equally plausible that the MW's satellite population is not
  representative of a typical MW-mass galaxy.  Here, we propose multi-object spectroscopy around
two nearby (D $< 30$\,Mpc) MW analog
  systems down to $M_r=-12$ ($r=20.5$).  Spectroscopy is necessary because  satellite
  galaxies are extremely difficult to distinguish from the thousands
  of higher redshift background galaxies via photometry alone.  We impose color cuts to
  improve the efficiency of finding low redshift satellites, however,
 there remain over 2500 candidate satellites around
  each analog system.  We will search for satellites out to the
  physical virial radius, 300 kpc, equivalent to 1 degree at these
  distances.  The AAT's AAOmega 2dF is by far the most efficient
  instrument for this work.  We
  request 3 nights with AAOmega to search for satellites
  around 2 MW analogs.  The proposed observations will be the
  complete satellite luminosity functions of any MW analog dow
  $M_r < -12$.
\end{abstract}
```

LaTex is an easy way to include Equations and Figures into text.

Abstract of Scientific Justification *(will be made publicly available for accepted proposals)*:
The Milky Way (MW) galaxy is host to two dozen dwarf galaxy satellites. The brightest of these satellites and their properties do not fully agree with predictions from galaxy formation models. While it is possible that model predictions are incorrect, it is equally plausible that the MW's satellite population is not representative of a typical MW-mass galaxy. Here, we propose multi-object spectroscopy around two nearby (D < 30 Mpc) MW analog systems down to $M_r = -12$ ($r = 20.5$). Spectroscopy is necessary because satellite galaxies are extremely difficult to distinguish from the thousands of higher redshift background galaxies via photometry alone. We impose color cuts to improve the efficiency of finding low redshift satellites, however, there remain over 2500 candidate satellites around each analog system. We will search for satellites out to the physical virial radius, 300 kpc, equivalent to 1 degree at these distances. The AAT's AAOmega 2dF is by far the most efficient instrument for this work. We request 3 nights with AAOmega to search for satellites around 2 MW analogs. The proposed observations will be the first complete satellite luminosity functions of any MW analog down to $M_r < -12$.

LaTex

LaTex is an easy way to include Equations and Figures into text.


```
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%
\begin{figure}[t]
\begin{center}
\begin{tabular}{c}
{\includegraphics[height=6.25cm]{figs/fig_sbMV_saga.pdf}}
{\includegraphics[height=5.6cm]{figs/nsf_figure2b.pdf}
}
\end{tabular}
\end{center}
\vspace{-0.5cm}
\caption{ \small{{\it Left:\/} Effective $r$-band surface brightness
  versus absolute magnitude for the Milky Way satellites compared to
  satellites around 6 of our host Milky Way analogs.  The proposed
  observations to $r = \rlim$ will detect satellites around analog
  Milky Ways down to $M_r < -11$ and will provide complete
  luminosity functions for all hosts down to $M_r < -12.5$. {\it
    Right:\/} Luminosity function of model Milky Way analogs,
    compared to the Milky Way and to preliminary results from two SAGA
    hosts.  Black dashed line and grey shaded regions indicate the
    mean and 1- and 2-sigma scatter for luminosity functions around a
    $K$-band selected sample of Milky-Way analogs, using our
    model for satellite populations (Mao, Williamson \& Wechsler in
    prep) combined with a simple assumption about the galaxy--halo
    connection.  The magenta dashed line shows the average
    luminosity function for halos with exactly 2 bright  ($M_r <
    -16.5$) satellites in the
    same model.}
\label{fig_mv_sigma}
}
\end{figure}

\section{Observing the Satellite Systems of Milky Way Analogs}\label{sec_obs}

\vskip -0.1cm
\noindent
We describe a three-phased observational program designed to achieve
the goals described above.  We first summarize results of a
pilot program to increase the efficiency of selecting satellite
galaxies based on SDSS photometry (\S\ref{ssec_pilot}).  Using these
```

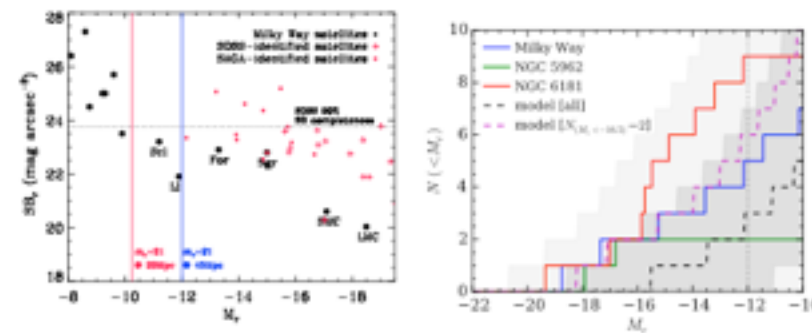


Figure 2: *Left:* Effective r-band surface brightness versus absolute magnitude for the Milky Way satellites compared to satellites around 6 of our host Milky Way analogs. The proposed observations to $r = 21$ will detect satellites around analog Milky Ways down to $M_r < -11$ and will provide complete luminosity functions for all hosts down to $M_r < -12.5$. *Right:* Luminosity function of model Milky Way analogs, compared to the Milky Way and to preliminary results from two SAGA hosts. Black dashed line and grey shaded regions indicate the mean and 1- and 2-sigma scatter for luminosity functions around a K-band selected sample of Milky-Way analogs, using our model for satellite populations (Mao, Williamson & Wechsler in prep) combined with a simple assumption about the galaxy–halo connection. The magenta dashed line shows the average luminosity function for halos with exactly 2 bright ($M_r < -16.5$) satellites in the same model.

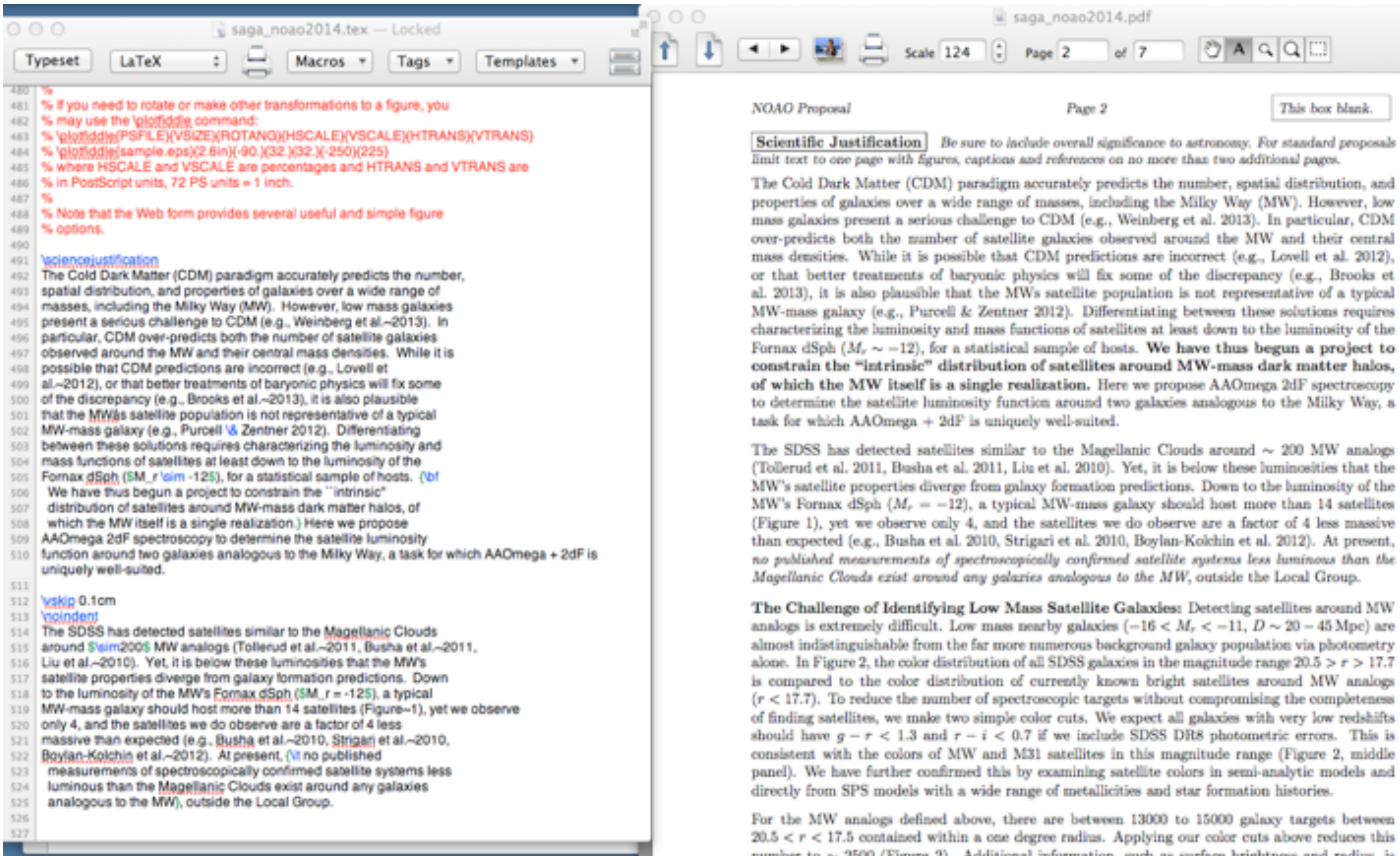
Broader Impacts: This provided partial postdoctoral support for L. Strigari (now an assistant professor at Texas A & M) & Y. Lu and a Stanford graduate student, and has led to nine publications. The PI gave public talks highlighting results from this funding. Our group also produced movies highlighting aspects of the funded work, which were featured in several articles by the popular press (risa.stanford.edu/milkyway). *Intellectual Merit:* Alvarez et al. (2009) showed that a wide range of reionization epochs is expected for MW-like halos. In Liu et al. (2011) and Busha et al. (2011b), we characterized the observed and predicted number of LMC and SMC-like satellite galaxies around MW-like host galaxies. In Strigari & Wechsler (2012), we exteded these statistics to as low luminosity as possible with existing SDSS data. In Busha et al. (2011a), we used the MW satellite population to constrain the *mass distribution* of the MW and its assembly history. In Li et al. (2013), we studied the environmental dependence of inhomogeneous reionization and its impact on satellites in MW halos. Wechsler is also the PI of collaborative grant NSF AST-1211838 entitled "Galaxies within Halos: A New Dark Energy Probe" (9/2012–8/2015). The scientific aims of this and the present proposal do not overlap. The first results from this work are published in Reddick et al. (2013), Rozo et al. (2014), and Rykoff et al. (2014).

4 Observing the Satellite Systems of Milky Way Analogs

Introduction to LaTeX

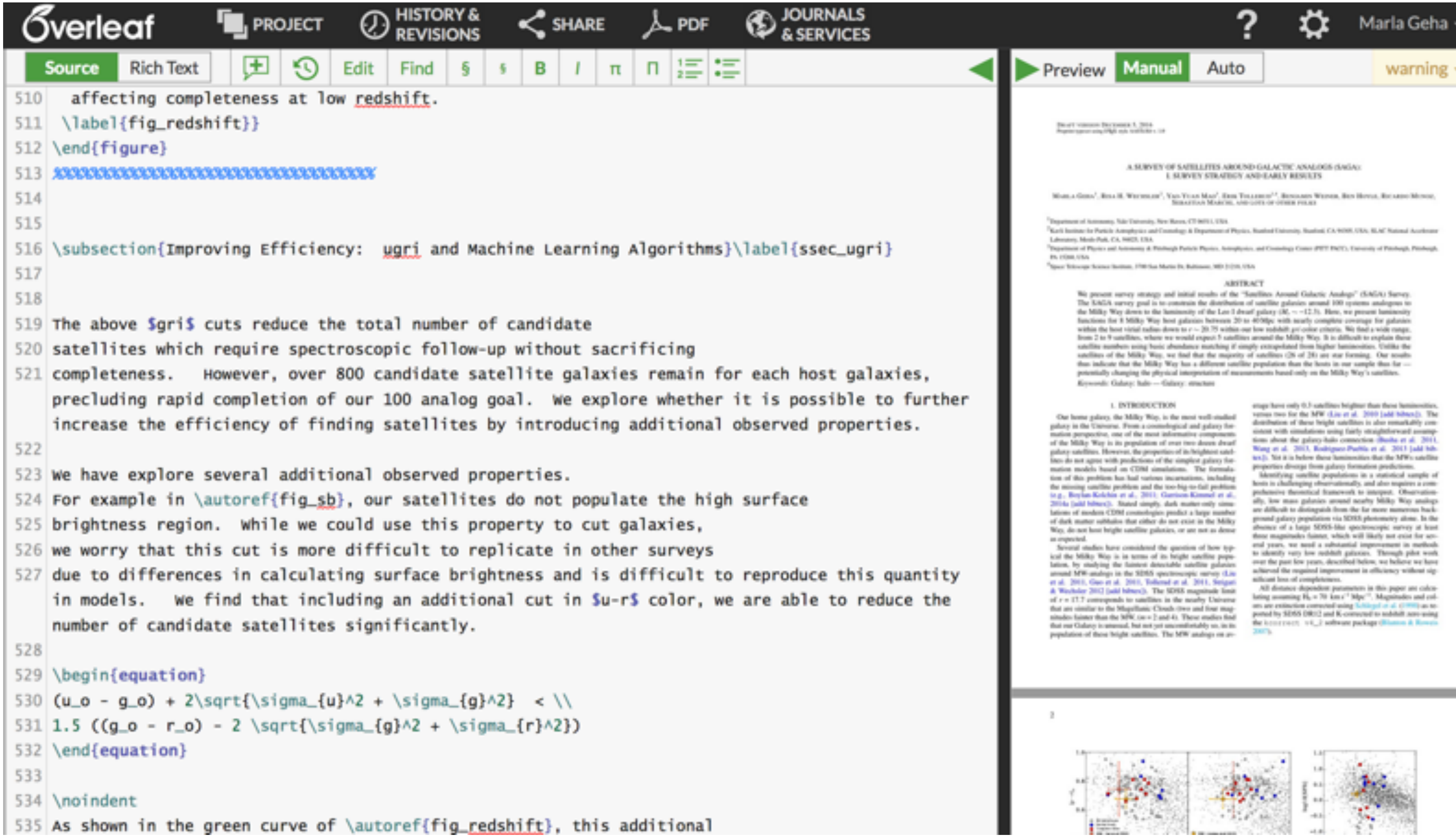
LaTeX can be run from the command line, but I prefer using **TeXshop**.

Need to download and install TeXShop: http://pages.uoregon.edu/koch/texshop/



Introduction to LaTeX

Alternatively, check out overleaf.com.   This allows everything to be run in a browser.



Introduction to LaTeX

To write equations in LaTeX, use math mode:

$ E = mc^2 $
$ F = \frac{Gm_i m_j }{r^2} $

$$E = mc^2$$

$$F = \frac{Gm_i m_j}{r^2}$$

$\int_{0}^{x} f(u) du$

$$\int_0^x f(u) du$$

$f = \sum_{i=0}^N \sqrt{[x_i} $

$$f = \sum_{i=0}^{N} \sqrt{x_i}$$

Greek Letters

α \alpha
β \beta
γ \gamma
δ \delta
ϵ \epsilon
ζ \zeta
η \eta
θ \theta
ι \iota
κ \kappa
λ \lambda
μ \mu
ν \nu

```latex
\begin{figure}[hbt]
\epsscale{1.00}
\plotone{figure3a.eps}
\caption{\small{ Distribution of known satellites for the Milky Way
   analog NGC 6181 ({\it middle panel}).  The three brightest
   satellites were found by SDSS, the two faintest satellites ({\it
     left panels}) were found as part of our pilot observations with
   WIYN HYDRA and MMT Hectospec.  The two faintest satellites fall in
   the range of colors defined in Figure~2.  There are over 2500
   sources consist with being satellites inside the red circle which
   is the virial radius of the host system of 300\kpc (1 degree).}}
\end{figure}
```

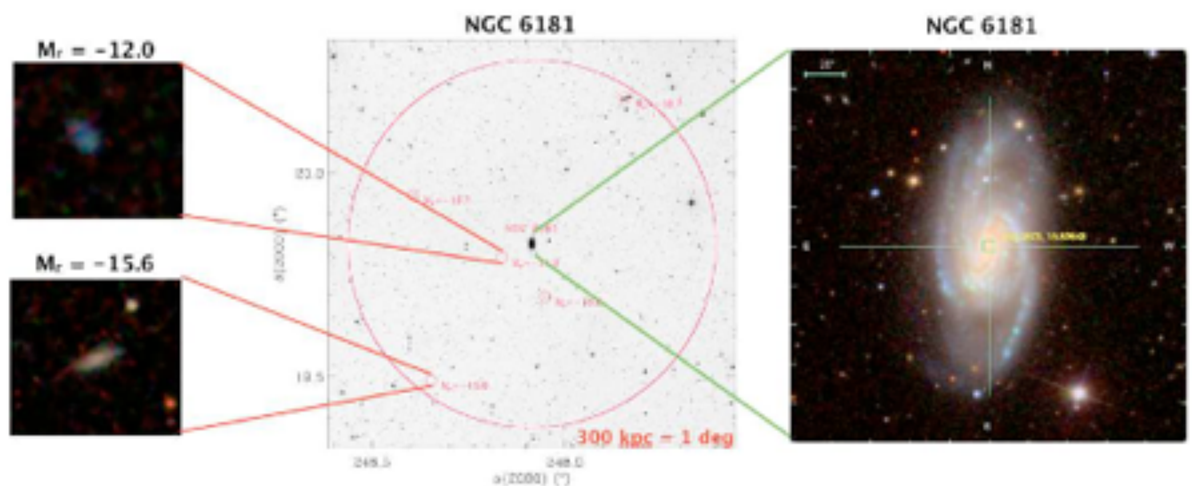


Figure 3: Distribution of known satellites for the Milky Way analog NGC 6181 (*middle panel*). The three brightest satellites were found by SDSS, the two faintest satellites (*left panels*) were found as part of our pilot observations with WIYN HYDRA and MMT Hectospec. The two faintest satellites fall in the range of colors defined in Figure 2. There are over 2500 sources consist with being satellites inside the red circle which is the virial radius of the host system of 300 kpc (1 degree).

Introduction to LaTeX

When writing science papers, BibTeX is an efficient, automated way to keep track of references:

1. Start a file which contains your references.   ADS contains a link with the formatted reference

Title:	Dwarf Galaxies with Optical Signatures of Active Massive Black Holes
Authors:	Reines, Amy E.; Greene, Jenny E.; Geha, Marla
Affiliation:	AA(National Radio Astronomy Observatory, Charlottesville, VA 22903, ... Fellow.; areines@nrao.edu), AB(Department of Astrophysical Sciences, Princeton, NJ 08544, USA), AC(Department of Astronomy, Yale Univer... 06520, USA)
Publication:	The Astrophysical Journal, Volume 775, Issue 2, article id. 116, 24 pp. (Homepage)
Publication Date:	10/2013
Origin:	IOP
Astronomy Keywords:	galaxies: active, galaxies: dwarf, galaxies: nuclei, galaxies: Seyfert
DOI:	10.1088/0004-637X/775/2/116
Bibliographic Code:	2013ApJ...775..116R

Abstract

We present a sample of 151 dwarf galaxies ($10^{8.5} \lesssim M_{stellar} \lesssim 10^{9.5} M_\odot$) that exhibit optical spe... of accreting massive black holes (BHs), increasing the number of known active galaxies in this sta... more than an order of magnitude. Utilizing data from the Sloan Digital Sky Survey Data Release 8 ... from the NASA-Sloan Atlas, we have systematically searched for active BHs in ~25,000 emission... stellar masses comparable to the Magellanic Clouds and redshifts z < 0.055. Using the narrow-line... [...]/Hα diagnostic diagram, we find photoionization signatures of BH accretion in 136 galaxies, a s... also exhibit broad Hα emission. For these broad-line active galactic nucleus (AGN) candidates, w... using standard virial techniques and find a range of $10^5 \lesssim M_{BH} \lesssim 10^6 M_\odot$ and a median of M_{BH}... also detect broad Hα in 15 galaxies that have narrow-line ratios consistent with star-forming galax... observations are required to determine if these are true type 1 AGN or if the broad Hα is from stell... median absolute magnitude of the host galaxies in our active sample is M_g = -18.1 mag, which is ... previous samples of AGN hosts with low-mass BHs. This work constrains the smallest galaxies th... BH, with implications for BH feedback in low-mass galaxies and the origin of the first supermassi...

Bibtex entry for this abstract   Preferred format for this abstract (see Preferences)

→

reines2013a

```
@ARTICLE{2013ApJ...775..116R,
   author = {{Reines}, A.~E. and {Greene}, J.~E. and {Geha}, M.},
    title = "{Dwarf Galaxies with Optical Signatures of Active Massive Black Holes}",
  journal = {\apj},
archivePrefix = "arXiv",
   eprint = {1308.0328},
 primaryClass = "astro-ph.CO",
 keywords = {galaxies: active, galaxies: dwarf, galaxies: nuclei, galaxies: Seyfert},
     year = 2013,
    month = oct,
   volume = 775,
      eid = {116},
    pages = {116},
      doi = {10.1088/0004-637X/775/2/116},
   adsurl = {http://adsabs.harvard.edu/abs/2013ApJ...775..116R},
  adsnote = {Provided by the SAO/NASA Astrophysics Data System}
}
```

2. Cite articles in the text as “As shown in this remarkable paper \citep{reines2013a}”
   or “\citet{reines2013a} shown this remakable thing”

3. When compiles this text will appear as “As shown in this remarkable paper (Reines et al. 2013)”
   or “Rienes et al. (2013) shown this remakable thing”

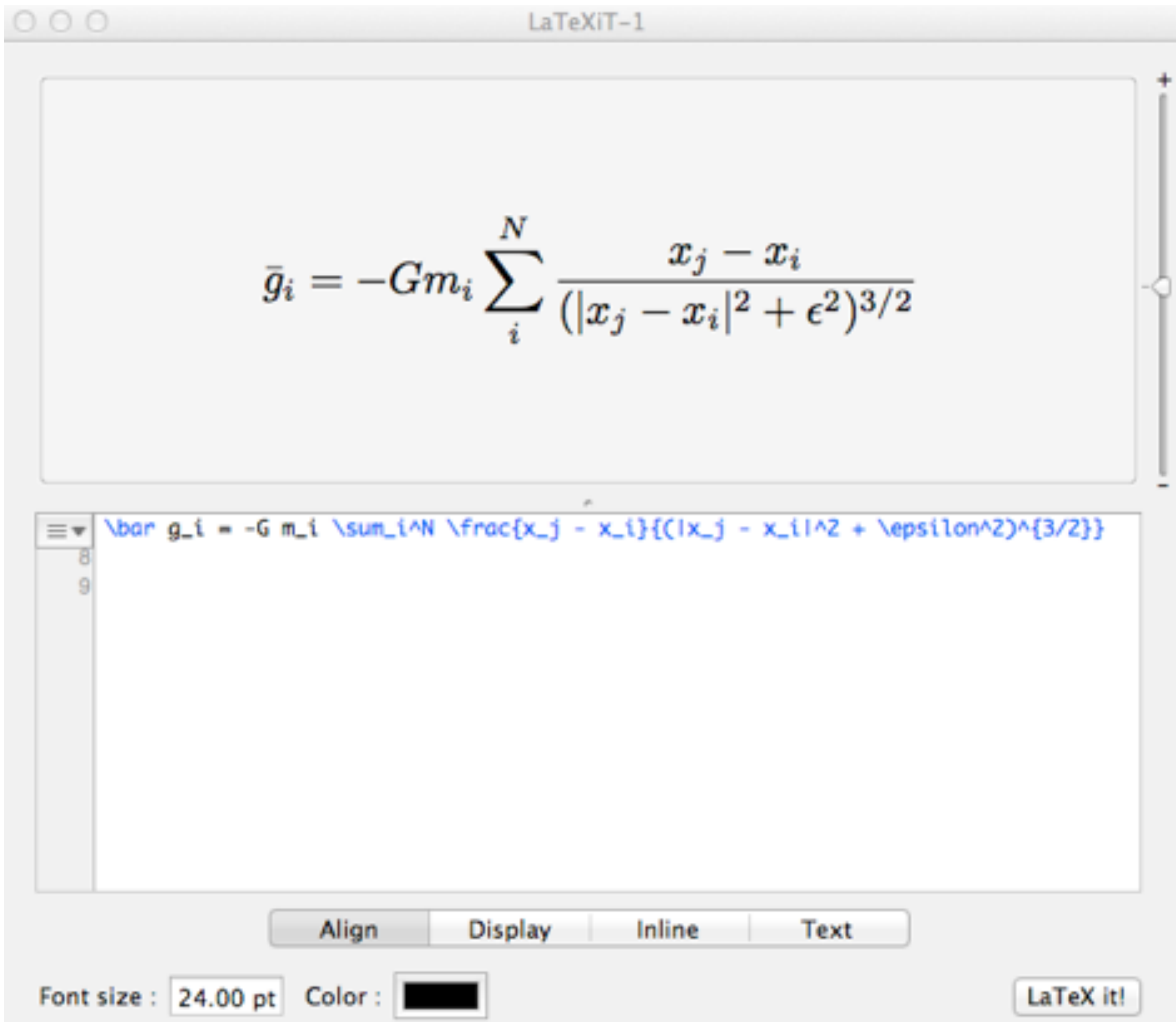
   ... and will create a reference list at end of paper

http://www.economics.utoronto.ca/osborne/latex/BIBTEX.HTM

Introduction to LaTeX

Another great tool is LaTeXit: make pdf or gifs of equations

http://www.chachatelier.fr/latexit/



Science Communication

Communicating science (both written and oral) is a critical skill for success in astrophysics.

(and pretty much any career)

Types of oral communication in astro/physics:

- Formal talks (senior thesis talk, colloquium)
- Informal talks ("tell me what you are working on")

Types of written communication in astro:

- Observing Proposals
- Grant proposals
- Research paper
- Job applications/grad school applications
- Emails!

A few ways to improve your communication skills:

1. Go to department talks. Note what you like/don't like
2. Read lots of papers, note what works and what doesn't work
3. Get specific examples of what you need to create
4. Get lots of feedback (ask friends to watch practice talk or read drafts).

Caltech Astronomy class on writing

http://www.astro.caltech.edu/~lah/ay31/

Ay 31
Writing in Astronomy
(Spring 2012)

Instructor: **Lynne Hillenbrand**

Meeting Time: Monday 3-4 pm

Course Description ...... Policies ...... Schedule ...... Advice ...... Resources

---

Course Description

This undergraduate course is intended to provide practical experience in the types of writing expected of professional astronomers. Example styles include research proposals, topical reviews, professional journal manuscripts, critiques, and articles for popular magazines such as Astronomy or Sky and Telescope. Each student will adopt one of these formats in consultation with the course instructor and write an original piece. An outline and several drafts reviewed by both a mentor familiar with the topic and the course instructor, are required. This course has limited enrollment and is open only to those students who have taken upper level astronomy courses (i.e. it is intended for Ay juniors and seniors). Ay 31 satisfies the written component of the Science Communication Requirement.

Policies

There are no problem sets or exams for this course! However, there are other requirements including:

- attendance at and participation in class meetings
- interaction with your chosen science mentor
- individual meetings with the course instructor

Other web resources

http://course1.winona.edu/mdelong/EcoLab/21 Suggestions.html

Twenty-One Suggestions for Writing Good Scientific Papers:

Notes on Writing Papers and Theses

1. Know your audience and write for that specific audience.

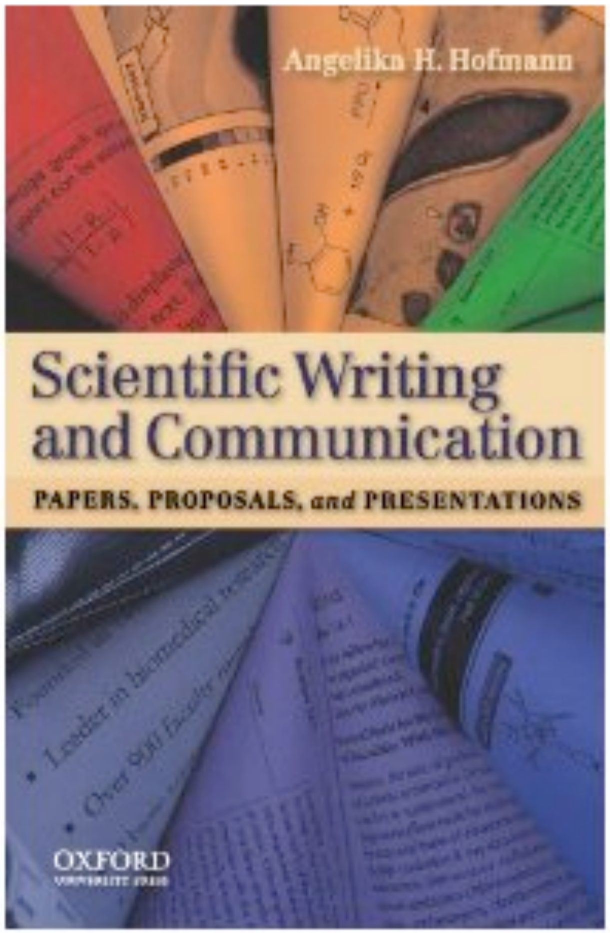
Scientific and technical writing can almost never be 'general purpose'; it must be written for a specific audience. For the kinds of writing addressed here, that audience will generally be the community of ecologists who read a particular journal or study a particular subject. This community is represented by your professor for class papers. In all cases, you must adopt the style and level of writing that is appropriate for your audience. Stylistic conventions and acceptable jargon can vary tremendously from one field to another, and to some extent, from one journal to another. If you are unfamiliar with the conventions of a field, study them as they are manifested in a selection of highly regarded papers and in the "**Instructions for Authors**" for key journals.

2. Your supervisor/professor is not here to teach you basic grammar and spelling.

The more time and emotional energy she or he spends on correcting basic English usage, the less remains for issues of content or fine-tuning. You are responsible for mastering the basics of the language; save your supervisor's time for more substantive issues. A few glitches and non-parallel tenses will sip through your own careful editing, but there is no excuse for frequent ungrammatical sentences. Similarly, with word processors and spellcheckers having become standard writing tools, typos or other spelling errors should be very rare. Use a spelling checker before submitting anything for anyone else's reading.

If you find you are about to submit a paper that you know contains poor writing, consider why you are doing so. If there is a writing problem with which you are having a hard time (for instance, organizing the structure of an argument in its most effective form), it is legitimate to submit this for someone else's review with the problem highlighted as a focused request for assistance. Otherwise, submitting a piece of writing with known errors or problems means either: (1) you do not consider your writing worth improving, (2) you do not respect the reader enough to present writing that is as good as you can make it, or (3) you are incapable of improving the writing. Every piece of writing, at some point, is as good as its writer can make it without outside review. That is the time to give it to your supervisor.

Strongly Recommended text on science writing



Scientific Writing and Communication: Papers, Proposals, and Presentations [Paperback]

Angelika H. Hofmann (Author)

★★★★★ (12 customer reviews) | Like (12)

List Price: ~~$39.95~~

Price: $27.36 & this item ships for **FREE with Super Saver Shipping**. Details

You Save: $12.59 (32%)

Science Writing

1. **Know your audience and write for that specific audience**.
2. **First impressions count!**
3. **Tell a compelling story. Use an outline to organize your ideas and writing**.
4. **Don't bury your lead!**
5. **Use Section headings to help tell your story**
6. **Captions should not merely name a table or figure, they should explain how to read it**.
7. **Do not use more words where fewer will do**.
8. **Use active verbs**
9. **Pay attention to tenses**.

1. Know your audience

Every piece of writing is written with a specific audience in mind. Find this out before starting.

Telescope observing proposal

Graduate school application

Research paper

Yale Daily News Article

Particularly for proposals and applications: Assume your readers are very busy and are reading many similar documents (e.g., Yale Astro Grad apps, 150 applications 6 committee members).

Make the readers job easier: use good layout, visually interesting figures, section headings, etc.

Just as everyone has a different learning style, your readers will have different 'reading styles'.
Try to accommodate as many types as possible.

2. First impressions count!

Research Statement: The Hierarchical Evolution of Dwarf Galaxies

1. Introduction

2. The Interaction Frequency of Dwarfs in Underdense Environments

COLLABORATIVE RESEARCH:
Distant Local Groups: Connecting the Predicted and Observed Satellite Galaxy Populations around Milky Way Analogs

1 Science Motivation

2. First impressions count!

have relatively precise line-of-sight distances to the tracers to formulate their 3-D distribution, and (3) it is now recognized that our view of the stellar halo changes according to what tracer (e.g., M giants, K giants, MSTO stars, RR Lyrae, BHB stars, etc.) is selected[2,135], which could explain why our view of the local stellar halo differs across the various studies noted above. In addition, one of the most fundamental properties that could help elucidate origin scenarios — the ages of halo stars — is extremely difficult to establish, even in a statistical sense: Our presently most reliable means by which to measure the ages of intermediate and old stellar populations is through analysis of color-magnitude diagrams (CMDs — e.g., via the position of the main sequence turn-off), which, however, are only sensibly interpretable when the CMD can be reliably created for stars at a common distance. It is not clear how much these observational challenges have contributed to uncertainties in our theoretical understanding of how stellar halos form. or example, ΛCDM-based numerical simulations by Co-I Johnston[14] predict that the outer stellar halo should be lumpy, flattened, and coursed by streams from satellite accretion, but these predictions are virtually untested at large Galactocentric distances because the current large-area photometric surveys are not faint enough to map standard tracers (MSTO, BHB's, RR Lyraes or M giants) beyond 100 kpc. Meanwhile, even the reality of the "dual halo" used to argue for multiple origin mechanisms by Carollo et al. has recently been challenged[131].

On the other hand, despite the greater distance of M31, studies of *its* stellar halo does confer several advantages: (1) Large fractions of the halo can be surveyed with limited sky coverage, (2) much cleaner samples of halo stars can be extracted, free of disk contamination, (3) a different, external perspective of a spiral galaxy halo is afforded, with different dependencies/degeneracies of line-of-sight differences with galactocentric radius, (4) we can survey the outer parts of M31 — to beyond 100 kpc — a regime presently poorly traced around the MW, and (5) the limited variation of line-of-sight distances of M31 stars empowers all of the tools we have for stellar population analysis of CMDs of field halo stars, and in particular, the opportunity to gauge the distributions of stellar *ages* in the M31 halo becomes possible. This advantage was exploited in the groundbreaking, deep Hubble Space Telescope (HST) imaging studies by Brown et al. (2006a,b, 2008) from which access to the very faint magnitudes of the M31 MSTO revealed that there are stars covering a range of ages in M31's stellar halo[7]. In particular, the deep HST fields on a strong tidal debris feature in M31 (the Giant Southern Stream — "GSS" — and associated debris; H11, H13s) show conclusive evidence of intermediate-age populations[12,13]. Unfortunately, these HST studies demand enormous investments of orbits, and, to date, cover only several very narrow pencil beams. This is not presently a viable path for a comprehensive assessment of age distributions across the M31 halo.

While large-area (SPLASH) and even panoramic (PAndaS) views of the M31 halo now exist, those optical data sets only reach a few magnitudes down the luminosity function and are thus beset by the familiar metallicity-age degeneracy on the RGB. Thus, we cannot get any information about the stellar ages from SPLASH or PAndaS imaging data alone, and we can only break this degeneracy through the hard work of obtaining spectroscopic metallicities (§6) — and not just [Fe/H], but also [α/Fe], since all metals contribute to the shape of the corresponding isochrones. As a result, so far the only observational evidence in M31 that can be brought to bear on the question of *in situ* vs. accreted vs. kicked-out formation mechanisms is gross structural properties (e.g., the change in surface brightness profile from sersic to power-law) and metallicity. These compare favorably to the results of the hydrodynamical ΛCDM simulations, but cannot provide a precision measurement and provide insufficient constraints[100]. And while the inner halo of M31 does contain abundant evidence of accretion through substructure, including the spectacular GSS[61], much of M31's halo remains unexplored to the depths necessary to detect more tenuous substructure. Therefore, our view is dominated by the high surface brightness GSS, whereas a more comprehensive understanding of the merger history — including less dramatic, older, and even more recent accretion events — remains largely unknown. There could be many stellar streams yet to be discovered, with potential implications for the missing satellite problem[77,106,136] and the hierarchical formation of galaxy halos. Naively we would expect to see more structure in intermediate age stars (assumed to be accreted, with possible contributions from kicked-out stars) compared to older populations (which could be a mixture of *in situ*, accreted and kicked out stars) and that the level of substructure should decreases as you go from outer halo (where accretion events dominate) to inner halo (with its possible mixture of all three mechanisms). But this level of detail is not likely to be revealed by simple imaging techniques until much deeper surface brightnesses in resolved stellar imaging can be reached, adequate to realize the gains in S/N conferred by accessing the jump in the luminosity function at the MSTO.

sample), local group analogs (MW-M31-M33 triplets), and a sample designed to test the impact of mass, environment, and the existence of massive satellites.

From a combination of observations and theory, the classical problem satellite abundance in the MW can be boiled down to a "Fornax problem." More specifically, why is it that, given an observed satellite galaxy with luminosity $\sim 10^7 L_\odot$ and $v_{max} = 20$ km s^{-1}, simulations predict the existence of scores of dark subhalos with similar mass, but observations constrain these objects to be virtually devoid of stars? **Using the statistics generated by the observational and theoretical work above, our final proposal objective is to distinguish between the following proposed explanations to the Fornax problem:**

- **Stochastic Galaxy Formation:** Perhaps the most straightforward theoretical explanation is a severe inefficiency or stochasticity in galaxy formation beginning at the Fornax dSph scale. Stochasticity can result from a variety of processes, including the formation environment of the dark matter halo, variation in the efficiency of feedback, and/or inhomogeneous reionziation.
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1. **Observe the Satellite Systems of Milky Way Analogs**
   - Obtain spectroscopic followup for a complete sample of satellites down to $\Delta m = 8$, for a host galaxy sample similar to the MW. From this sample, we will determine the full probability

5. Use Section headings to help tell your story

Scientific Justification *Be sure to include overall significance to astronomy. For standard proposals limit text to one page with figures, captions and references on no more than two additional pages.*

Since 2005, systematic searches of the sky have revealed 14 dwarf galaxies orbiting the Milky Way, more than doubling the known number. These "ultra-faint" galaxies are less luminous than any other known galaxy ($10^{3-4} L_{sun}$) and have emerged as the most dark matter-dominated galaxies in the known Universe (Martin et al. 2008, Geha et al. 2009, Simon et al. 2010). All of the ultra-faint galaxies were discovered as slight over-densities of resolved stars in the Sloan Digital Sky Survey (SDSS). However, the SDSS covers only 25% of sky and its limiting magnitude of $r \sim 22$ is sufficient to reveal the faintest satellites only out to ~40 kpc. Thus, less than 0.1% of the Milky Way's virial volume has been mined for the faintest dwarf galaxy satellites (Walsh, Willman & Jerjen 2009). Characterizing the total number and spatial distribution of ultra-faint dwarf galaxies throughout the Milky Way volume is necessary for meaningful quantitative comparisons with cosmological and galaxy formation models.

An unbiased measurement of the ultra-faint galaxy population requires imaging data to deeper magnitudes, and thus deeper into the Milky Way's halo, as compared to SDSS. Optimistic predictions for the number of Milky Way satellites suggest at most a single dwarf galaxy per 100 square degrees down to very faint limits (Tollerud et al. 2008). Quantifying the total number of Milky Way dwarf galaxies therefore requires deep, wide field imaging. One of us (BW) has developed a sophisticated algorithm to search for ultra-faint galaxies and quantify the completeness of these searches (Walsh, Willman & Jerjen 2009).

We have applied the above search algorithm to the point source catalog of the Red Sequence Cluster Survey 2 (RCS2), which covers ~ 750 deg^2 down to $r = 24$, two magnitudes fainter than SDSS. (Catalogs obtained via private communication with M. Gladders). Due to its photometric depth, the relative volume around the Milky Way probed by this survey is comparable to that of SDSS.

Our RCS2 search has produced a number of promising candidates at distances beyond the known population of ultra-faint galaxies. Figure 1 shows one such candidate, including the spatial distribution of possible member stars and a color-magnitude diagram of stars in the detected overdensity. These discovery figures bear a striking resemblance to those from the discovery of Leo T in SDSS data (Figure 1), but are at almost twice the distance (600-1000 kpc as compared to 420 kpc). Because the prospect of finding dwarfs with fainter than $M_V = -7$ at $d > 500$ kpc is compelling, we have selected a total of 2 such candidates to study in this proposal.

A hallmark of our detection algorithm is its stringent requirements for candidate identification. Any region of sky flagged as a candidate is a real physical overdensity of point sources. However, deep, follow-up imaging is needed to determine whether this spatial clustering of point sources is revealing the presence of a dwarf galaxy, of a star cluster, or of unresolved galaxies. Unresolved galaxies are a particularly problematic contaminant at magnitudes below r~23, where the number counts of unresolved galaxies rise significantly. Post-SDSS searches for extremely low surface brightness galaxies, including our search of RCS2, must overcome this overwhelming number of unresolved galaxies at faint magnitudes to move the field forward. This proposal is the first to address this problem in the context of ultra-faint galaxy searches.

We propose deep Gemini GMOS and NIRI imaging of two ultra-faint dwarf galaxy candidates. These images will be used to confirm the reality of these objects by revealing the color-magnitude sequence of their constituent stars. If confirmed, these will be the first Milky Way ultra-faint galaxies discovered outside of SDSS data, and will be by far the most distant of the lowest luminosity systems. If ruled out as dwarf galaxies, then these observations will inform our ongoing and future searches of deep, wide-field data for Milky Way satellites.

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Dwarf elliptical galaxies (dEs) are the dominant galaxy type in the local Universe, accounting for more than 75% of objects brighter than $M_V < -14$ in nearby galaxy clusters (see Ferguson & Binggeli 1994 for a review). It is not yet known whether dEs play an important role as building blocks in hierarchical galaxy formation or represent the end products of galaxy harassment and stripping of a progenitor galaxy population. Recent major-axis spectroscopy of dEs outside the Local Group have provided an unexpected picture of dE kinematics and have effectively rule out currently proposed models of dE formation (Geha, Guhathakurta & van der Marel 2003). However, it is unclear whether or not such single-slit observations are providing an accurate picture of the overall dynamics. To allow a more critical review of dE galaxy formation models, we propose the first integral field spectroscopic observations of two Virgo Cluster dEs with the GMOS-N IFU.

Models of Dwarf Elliptical Galaxy Formation: Formation scenarios for the origin of dE galaxies lie broadly in two very distinct categories: (1) dEs are old, primordial objects, and (2) dEs have recently evolved or transformed from a progenitor galaxy population. The former scenario predicts that dEs should be less spatially clustered than normal elliptical or spiral galaxies (Dekel & Silk 1986). Since dE galaxies are observed to be *more* spatially clustered than either ellipticals or spirals, current models favor dE formation from a progenitor galaxy population. Moore et al. (1998) suggest that galaxy harassment in clusters can morphologically transform a spiral galaxy into a dwarf elliptical. In these simulations, harassment partially disrupts the rotational motion of the progenitor galaxy while increasing velocity dispersions. These simulations predict that, while dEs may not be rotationally-supported, a significant percentage of the progenitor's rotation will be preserved.

Dwarf Elliptical Kinematics: Rotation versus Anisotropy: Major-axis spectroscopy of dEs outside the Local Group have provided an unexpected picture of dE kinematics (Geha et al. 2002, 2003; Pedraz et al. 2002; de Rijcke et al. 2001). Unlike the Local Group dEs which are not supported by rotation, a fraction of dE galaxies observed in the Virgo Cluster are roughly consistent with rotational flattening, while the remaining dEs have no detectable major axis rotation (Figure 1). Rotation velocities for dEs with little rotation are upper limits, those for rotating dEs are lower limits since our observations do not reach the turnover radius. Thus, rotating and non-rotating dEs appear to be two separate classes of objects. *Despite this dichotomy in kinematics, dEs with and without rotation are virtually identical in all other observable properties,* such as position in the Fundamental Plane, morphology and local environment (Geha et al. 2003).

The rotation properties of Virgo dEs do not appear to be correlated with any other dE property. This observation in combination with the possible dichotomy of rotational support, presents a significant challenge to any model of dE galaxy formation. Formation models do not naturally predict a dichotomy in rotational properties. However, invoking two separate mechanisms must also explain the similarity in internal properties between these two dE types. In addition, the harassment scenario and other dE formation models (eg. gas stripping of dIrr, gas evacuation via supernova-driven winds) have difficulty explaining the large fraction of dEs with extremely low rotation velocities. Plausible dE progenitors such as spiral and dIrr galaxies have significant

5. Use Section headings to help tell your story

have relatively precise line-of-sight distances to the tracers to formulate their 3-D distribution, and (3) it is now recognized that our view of the stellar halo changes according to what tracer (e.g., M giants, K giants, MSTO stars, RR Lyrae, BHB stars, etc.) is selected[2,135], which could explain why our view of the local stellar halo differs across the various studies noted above. In addition, one of the most fundamental properties that could help elucidate origin scenarios — the ages of halo stars — is extremely difficult to establish, even in a statistical sense: Our presently most reliable means by which to measure the ages of intermediate and old stellar populations is through analysis of color-magnitude diagrams (CMDs — e.g., via the position of the main sequence turn-off), which, however, are only sensibly interpretable when the CMD can be reliably created for stars at a common distance. It is not clear how much these observational challenges have contributed to uncertainties in our theoretical understanding of how stellar halos form. or example, ΛCDM-based numerical simulations by Co-I Johnston[14] predict that the outer stellar halo should be lumpy, flattened, and coursed by streams from satellite accretion, but these predictions are virtually untested at large Galactocentric distances because the current large-area photometric surveys are not faint enough to map standard tracers (MSTO, BHB's, RR Lyraes or M giants) beyond 100 kpc. Meanwhile, even the reality of the "dual halo" used to argue for multiple origin mechanisms by Carollo et al. has recently been challenged[131].

On the other hand, despite the greater distance of M31, studies of *its* stellar halo does confer several advantages: (1) Large fractions of the halo can be surveyed with limited sky coverage, (2) much cleaner samples of halo stars can be extracted, free of disk contamination, (3) a different, external perspective of a spiral galaxy halo is afforded, with different dependencies/degeneracies of line-of-sight differences with galactocentric radius, (4) we can survey the outer parts of M31 — to beyond 100 kpc — a regime presently poorly traced around the MW, and (5) the limited variation of line-of-sight distances of M31 stars empowers all of the tools we have for stellar population analysis of CMDs of field halo stars, and in particular, the opportunity to gauge the distributions of stellar *ages* in the M31 halo becomes possible. This advantage was exploited in the groundbreaking, deep Hubble Space Telescope (HST) imaging studies by Brown et al. (2006a,b, 2008) from which access to the very faint magnitudes of the M31 MSTO revealed that there are stars covering a range of ages in M31's stellar halo[7]. In particular, the deep HST fields on a strong tidal debris feature in M31 (the Giant Southern Stream — "GSS" — and associated debris; H11, H13s) show conclusive evidence of intermediate-age populations[12,13]. Unfortunately, these HST studies demand enormous investments of orbits, and, to date, cover only several very narrow pencil beams. This is not presently a viable path for a comprehensive assessment of age distributions across the M31 halo.

While large-area (SPLASH) and even panoramic (PAndaS) views of the M31 halo now exist, those optical data sets only reach a few magnitudes down the luminosity function and are thus beset by the familiar metallicity-age degeneracy on the RGB. Thus, we cannot get any information about the stellar ages from SPLASH or PAndaS imaging data alone, and we can only break this degeneracy through the hard work of obtaining spectroscopic metallicities (§6) — and not just [Fe/H], but also [α/Fe], since all metals contribute to the shape of the corresponding isochrones. As a result, so far the only observational evidence in M31 that can be brought to bear on the question of *in situ* vs. accreted vs. kicked-out formation mechanisms is gross structural properties (e.g., the change in surface brightness profile from sersic to power-law) and metallicity. These compare favorably to the results of the hydrodynamical ΛCDM simulations, but cannot provide a precision measurement and provide insufficient constraints[120]. And while the inner halo of M31 does contain abundant evidence of accretion through substructure, including the spectacular GSS[61], much of M31's halo remains unexplored to the depths necessary to detect more tenuous substructure. Therefore, our view is dominated by the high surface brightness GSS, whereas a more comprehensive understanding of the merger history — including less dramatic, older, and even more recent accretion events — remains largely unknown. There could be many stellar streams yet to be discovered, with potential implications for the missing satellite problem[77,106,138] and the hierarchical formation of galaxy halos. Naively we would expect to see more structure in intermediate age stars (assumed to be accreted, with possible contributions from kicked-out stars) compared to older populations (which could be a mixture of *in situ*, accreted and kicked out stars) and that the level of substructure should decreases as you go from outer halo (where accretion events dominate) to inner halo (with its possible mixture of all three mechanisms). But this level of detail is not likely to be revealed by simple imaging techniques until much deeper surface brightnesses in resolved stellar imaging can be reached, adequate to realize the gains in S/N conferred by accessing the jump in the luminosity function at the MSTO.

sample), local group analogs (MW-M31-M33 triplets), and a sample designed to test the impact of mass, environment, and the existence of massive satellites.

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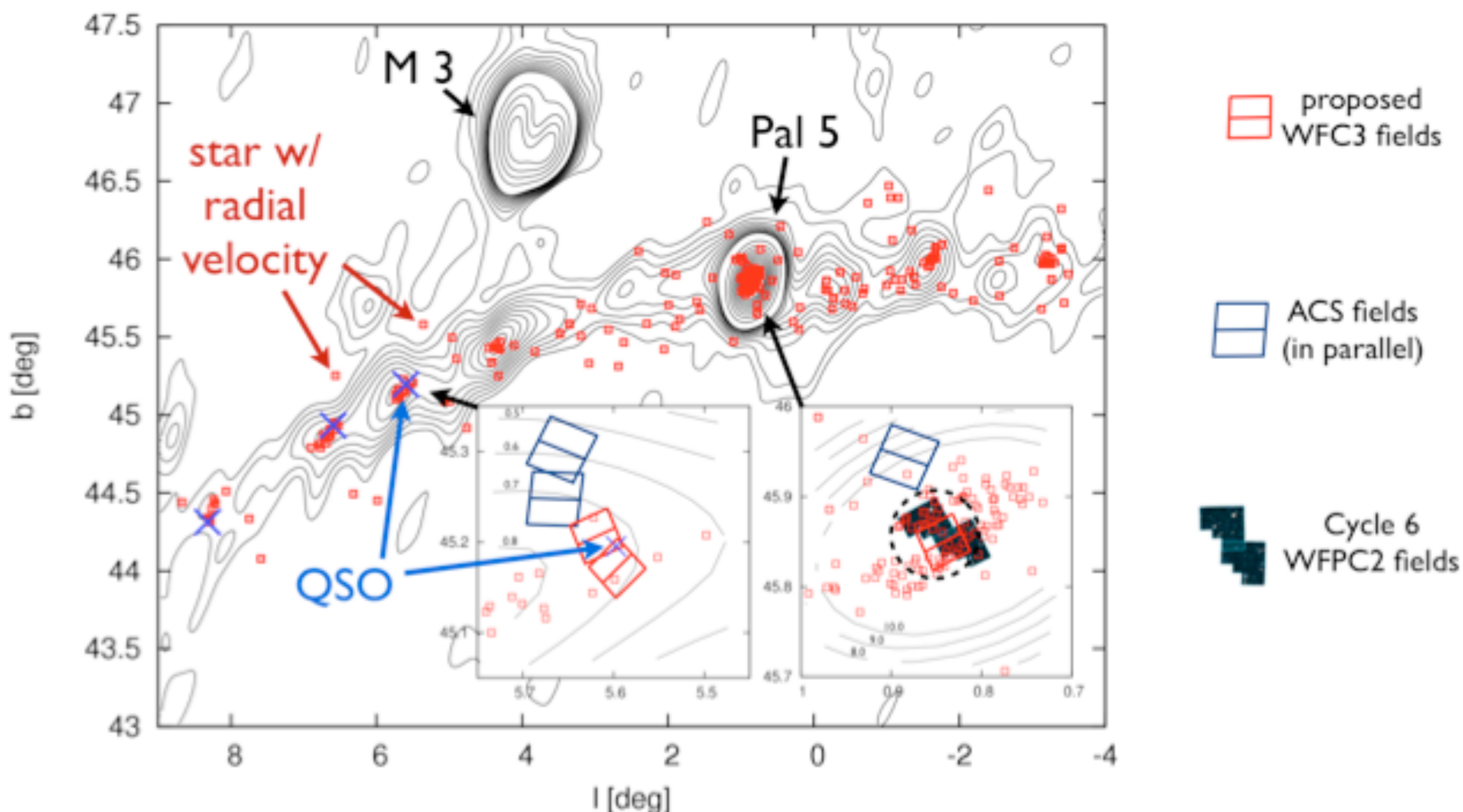
6. Captions should not merely name a table or figure, they should explain how to read it.

Figures should tell their own story.

Figure caption should state the point of the figure

Do not over-complicate a plot.



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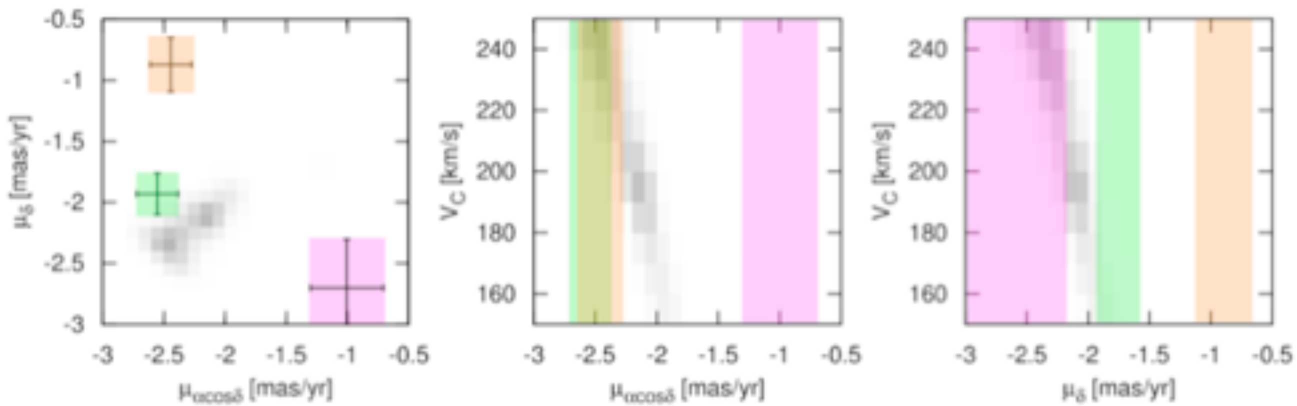

Figure 2: *Left:* Expected PM from our TT modeling. The grey scale gives goodness-of-fit values of our TT models to the published observational data, where dark grey corresponds to model parameters which reproduce the observational data well. Models with a PM of ≈ 2 and ≈ 2.5 mas/yr in both coordinates stand out. With our proposed PM measurement we will be able to distinguish between these two cases. Black data points give the three available (ground-based) PM measurements from the literature with their stated uncertainties (cf. Odenkirchen et al. 2001). These values are in contradiction with our model predictions, and would necessitate unrealistic Galactic circular velocities or a very strong flattening of the Galactic potential, inconsistent with other studies. *Middle:* Predicted dependence of Pal 5's PM (here $\mu_{\alpha\cos\delta}$) on the Galactic circular velocity, V_C, at the Galactocentric radius of Pal 5 (about 18.6 kpc). The grey scale is the same as in the left panel. The best fitting models with ≈ 2.0 and ≈ 2.5 mas/yr in both coordinates correspond to V_C of about 190 ± 15 km/s and 240 ± 10 km/s, respectively. Shaded regions show to which V_C the literature PM values correspond. *Right:* The same as in the middle panel but for μ_δ. The corresponding values of V_C from the literature PM are in contradiction for what is found in the other PM coordinate. These measurements may well be prone to systematic errors as they rely on a small number of very faint background galaxies. Our proposed PM measurement with HST/WFC3 will rely on a bright QSO and on more than 100 background galaxies.

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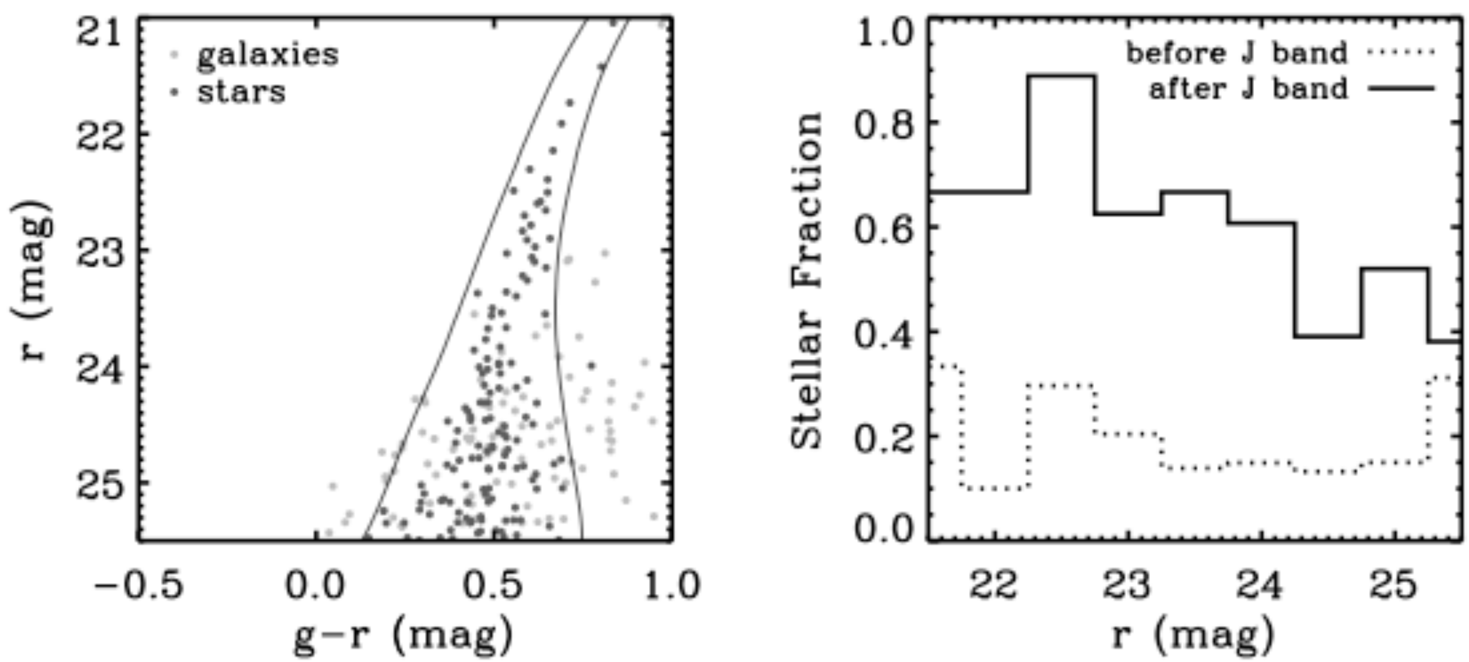

Figure 3: Plotted on the left is the $g - r$ CMD presented in Figure 2, after first selecting objects within the isochrones plotted in the $g - J$ CMD. Since many of the galaxies do not lie on the stellar locus (and many are fainter than $J = 24$), the number of galaxy counts is severely reduced and the underlying stellar population is revealed. Plotted on the right is the stellar fraction of point sources, before and after our $g - J$ cut. By including the NIR information many galaxies are eliminated, increasing the stellar fraction by a factor of 2-3.

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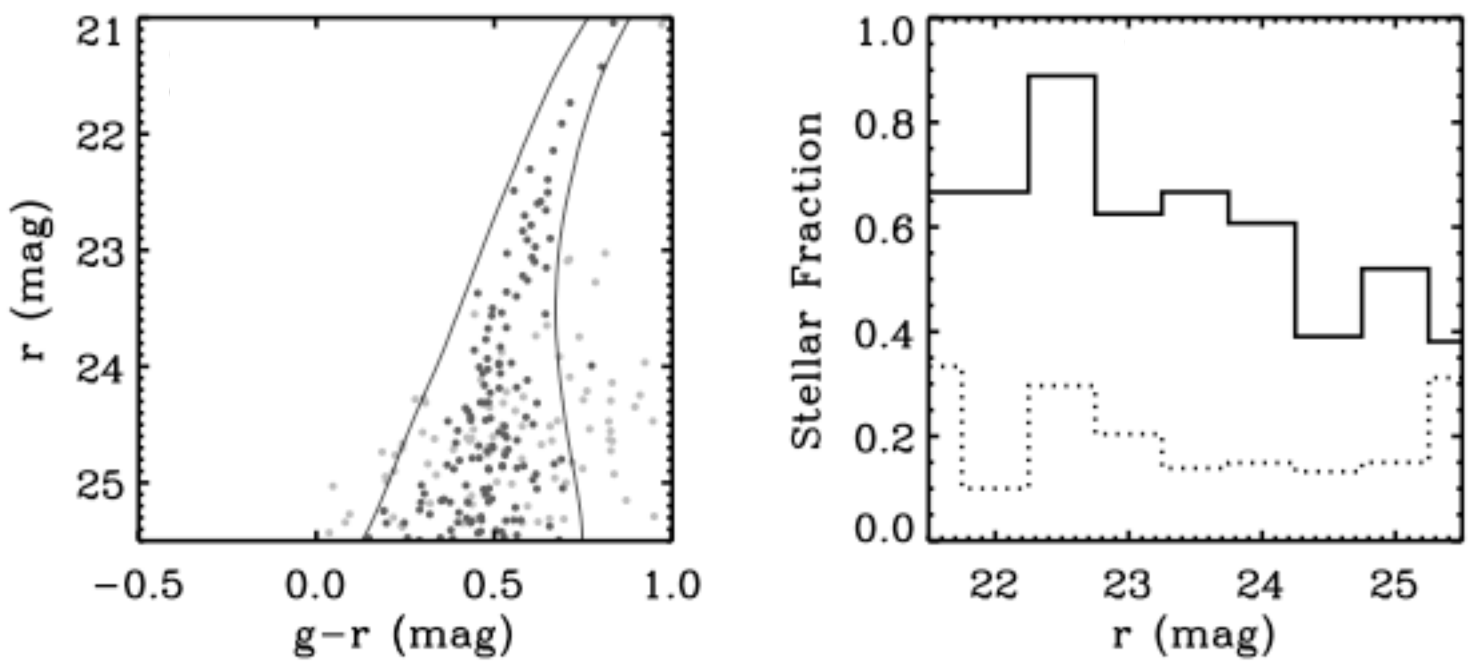

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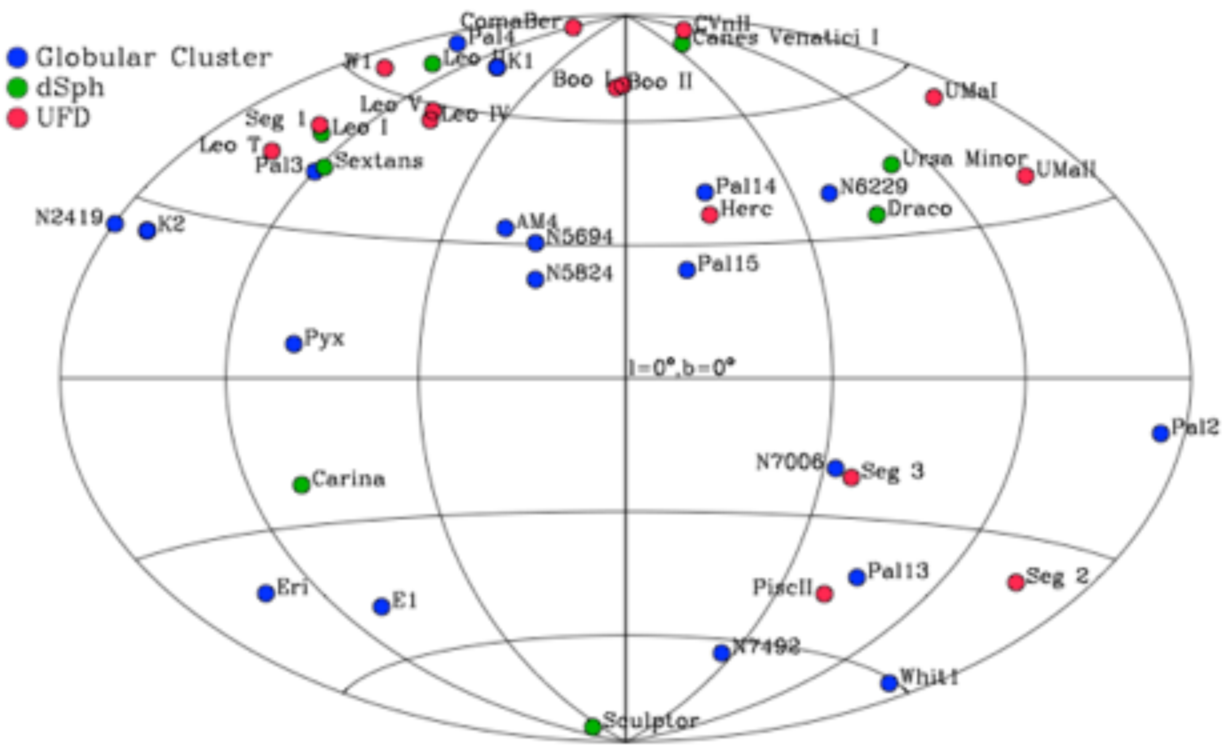


Figure 1: Locations of all known globular clusters (blue triangles), dSphs (green circles) and ultra-faint galaxies (red circles) known around the Milky Way. The larger number of objects at high galactic longitude is due to discoveries in the SDSS. Our Megacam survey program will be the first deep, wide-field, homogeneous study of all known stellar overdensities in the Milky Way halo.

7. Do not use more words where fewer will do.

Unnecessary Words:

actually	really
basically	very
essentially	quite

It is well known that there are two types of galaxies

There are two types of galaxies

Eddies have been shown to vary depending on the time of year.

Eddies vary depending on the time of year.

7. Do not use more words where fewer will do.

Writing Principle: Place old, familiar and short information at the beginning of a sentence.

Writing Principle: Place new, complex, or long information at the end of a sentence.

✗ Due to the nonlinear and hence complex nature of ocean currents, modeling these currents in tropical Pacific is difficult

✓ Modeling ocean currents in the topical Pacific is difficult due to their nonlinear and hence complex nature.

7. Do not use more words where fewer will do.

Writing Principle: Avoid interruptions between the subject and verb.

✗ We quantitatively compared, using a model-based Bayesian method relying on numerical simulations, the different introduction scenarios for the Western European population.

✓ Using a model-based Bayesian method relying on numerical simulations, we quantitatively compared the different introduction scenarios for the Western European population.

8. Use active verbs

✗ Their **suggestion** for us was a different **analysis** of the data.

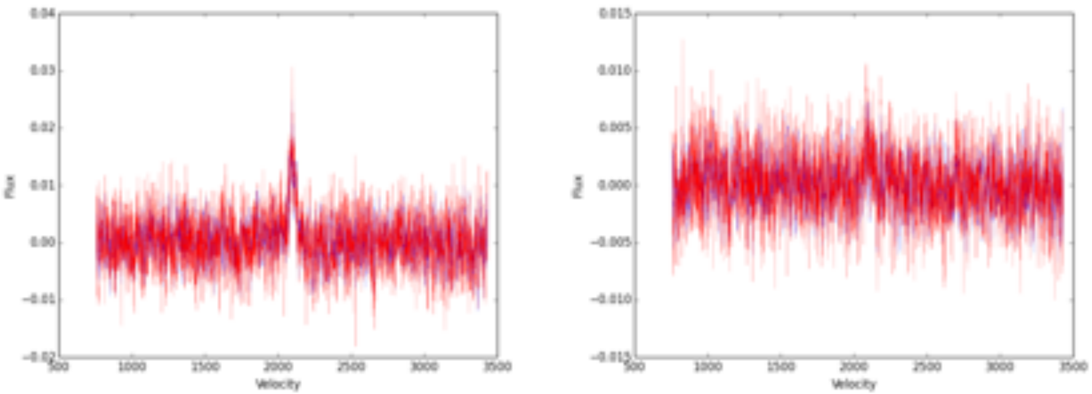
✓ They suggested that we analyze the data differently.

✗ An increase in temperature occurred.

✓ Temperature increased.

PS#9 Write-Up

A fraction of the PS#9 grade will be for clarity of your write-up. This includes explaining each step of your analysis and showing well-constructed plots.

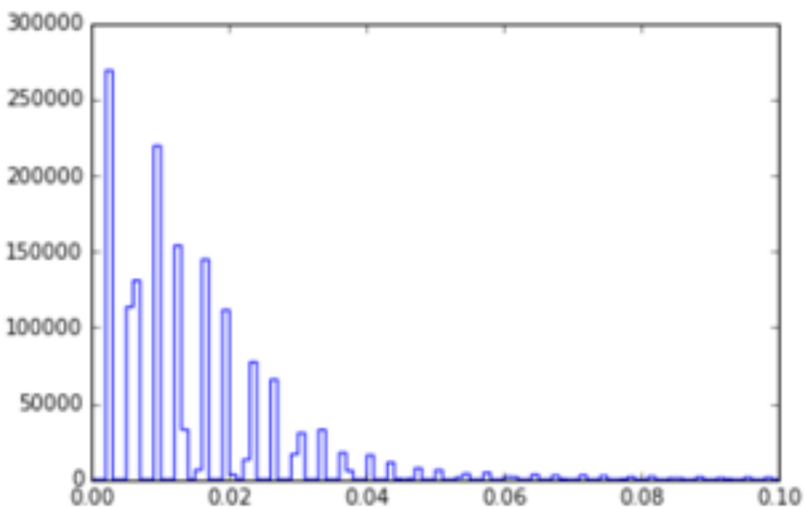


Problem 12. The off-center pointing seems to be a non-detection. And here's a catalogue of fake profiles with various total flux-levels.

good: plots are labeled

bad: Partial sentences included in the caption. Plot could include legend to make results more clear.

Figure 2: A histogram of red data



good: plots are labeled

bad: No axis labels, y-axis might be better to use scientific notation.

PS#9 Write-Up

Table 1: Fluxes of the stars

idx	r	g
0	6.48347828248	4.91413135624
1	18.1778933243	10.5986573736
2	10.0976575004	2.60762888585
3	14.5883837984	9.18641976402
4	7.36321548036	5.61721349402
5	73.7154718636	41.3702813276
6	17.2799895662	4.56092376821
7	12.6331866323	9.76527500525
8	11.3870391409	6.76078392366
9	8.07746594508	6.35808327473
10	3.66903675351	2.88969898053

Significant digits:

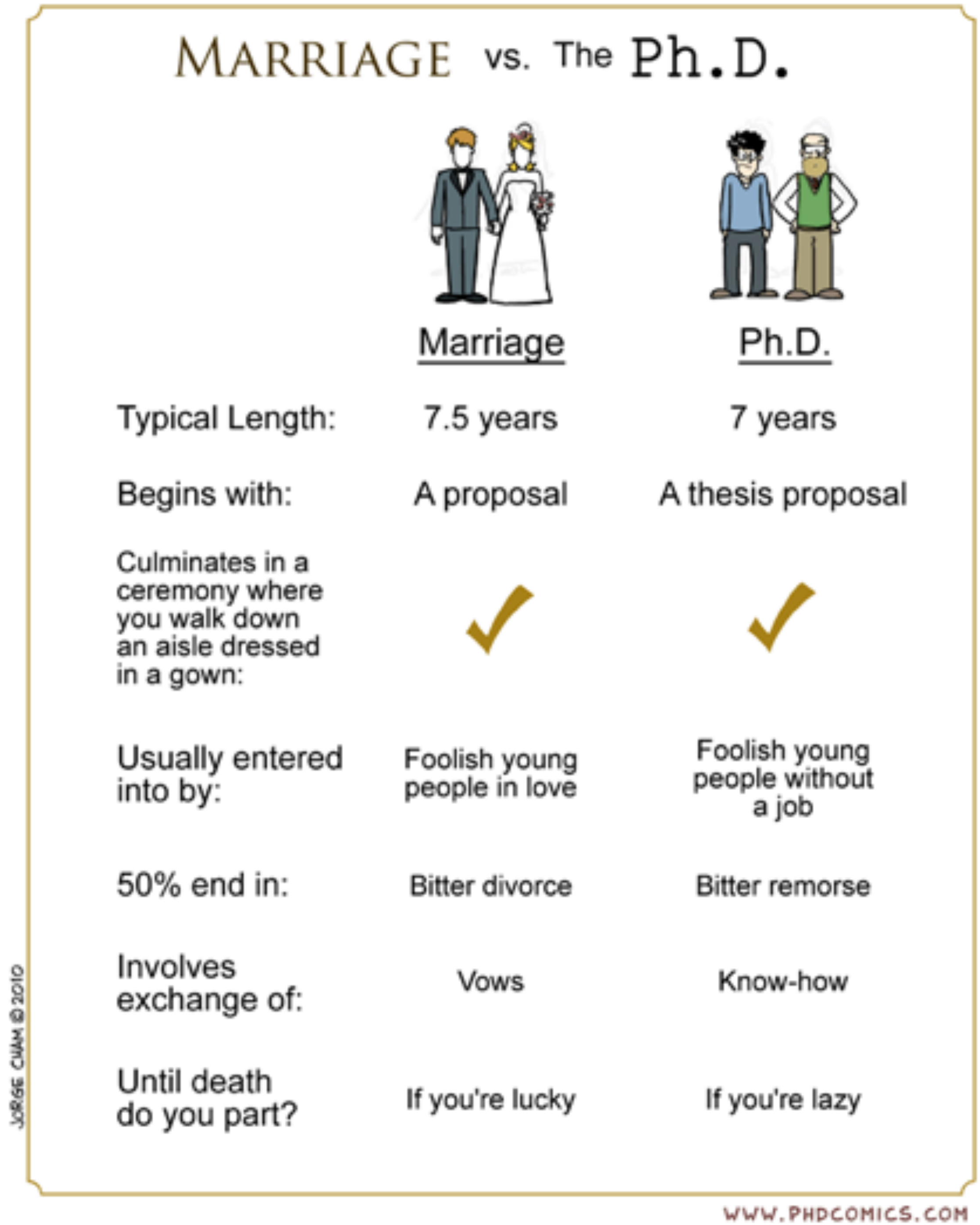
Do not show more significant digits than needed.

Show one additional significant digit than the accuracy of your data.

b. The star temperatures were calculated using Wien's law. The result was:

Star Name	Temperature (K)
Sed1	8795.8750379132543
Sed2	7179.9950482792765
Sed3	3516.0038797284187

What is Graduate School like?



Summer Research Opportunities

Deadlines for 2017 summer research are approaching!

Listing of Summer Research Opportunities from NSF:
https://www.nsf.gov/crssprgm/reu/list_result.jsp

Listing of Summer internships from NASA:
https://intern.nasa.gov/

There are also grants available through your college to do research on campus