

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.

The screenshot shows the Cornell University Library logo and the text "Cornell University Library". On the right, it says "We gratefully acknowledge support from the Simons Foundation and Yale University". Below this is a red navigation bar with "arXiv.org > astro-ph" on the left and search options ("Search or Article ID", "All papers", "Help | Advanced search") on the right. The main content area is titled "Astrophysics (since Apr 1992)".

Astrophysics (since Apr 1992)

For a **specific paper**, enter the identifier into the top right search box.

- **Browse:**
 - [new](#) (most recent mailing, with abstracts)
 - [recent](#) (last 5 mailings)
 - [current month's](#) astro-ph listings
 - specific year/month:
2016 12
- **Catch-up:**
Changes since: 30 11 (Nov) 2016 , view results without abstracts
- **Search within the astro-ph archive**
- **Article statistics by year:**
[2016](#) [2015](#) [2014](#) [2013](#) [2012](#) [2011](#) [2010](#) [2009](#) [2008](#) [2007](#) [2006](#) [2005](#) [2004](#) [2003](#) [2002](#) [2001](#) [2000](#) [1999](#) [1998](#) [1997](#) [1996](#) [1995](#) [1994](#)
[1993](#) [1992](#)

Categories within Astrophysics

- **astro-ph.GA – Astrophysics of Galaxies** ([new](#), [recent](#), [current month](#))
Phenomena pertaining to galaxies or the Milky Way. Star clusters, galactic nebulae, the interstellar medium, clouds, dust. Galactic structure, formation, dynamics. Galactic nuclei, bulges, disks, halo. Active Galactic Nuclei, supermassive black holes, quasars. Gravitational lens systems. The Milky Way and its contents
- **astro-ph.CO – Cosmology and Nongalactic Astrophysics** ([new](#), [recent](#), [current month](#))
Phenomenology of early universe, cosmic microwave background, cosmological parameters, primordial element abundances, extragalactic distance scale, large-scale structure of the universe. Groups, superclusters, voids, intergalactic medium. Particle

<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](#)

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Databases to query: [Astronomy](#) [Physics](#) [arXiv e-prints](#)

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

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(OR AND [simple logic](#))

(Combine with: OR AND)

Publication Date between

and

(MM) (YYYY)

Enter Title Words

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(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

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

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 ( $D < 30\text{ Mpc}$ ) 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 down  
to  $M_r < -12$ .  
  
\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 ($D < 30\text{ Mpc}$) 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.

```
design.tex — Edited
Typeset LaTeX Macros Tags Templates
1 %
2 %
3 %
4 \begin{figure}[t]
5 \begin{center}
6 \begin{tabular}{c}
7 \includegraphics[height=6.25cm]{fig_sbMV_saga.pdf}\\
8 \includegraphics[height=5.6cm]{fig/nsf_figure2b.pdf}
9 \end{tabular}
10 \end{center}
11 \vspace{-0.5cm}
12 \caption{\small\textbf{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 $M_r < -12.5$. \textbf{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.}
13 \label{fig_mv_sigma}
14 \end{figure}
15 \section{Observing the Satellite Systems of Milky Way Analogs}\label{sec_obs}
16 \vskip -0.1cm
17 \noindent
18 We describe a three-phased observational program designed to achieve
19 the goals described above. We first summarize results of a
20 pilot program to increase the efficiency of selecting satellite
21 galaxies based on SDSS photometry (\S\ref{ssec_pilot}). Using these
```

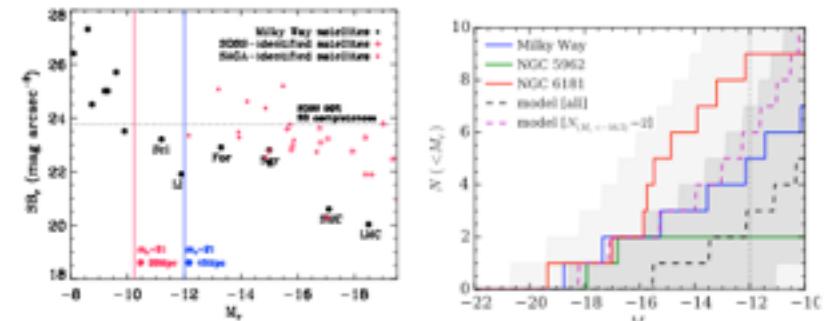


Figure 2: *Left:* Effective r -band surface brightness versus absolute magnitude for the Milky Way satellites compared to satellites around 6 of our host Milky Way analogs. The proposed observations to $r = 21$ will detect satellites around analog Milky Ways down to $M_r < -11$ and will provide complete 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.

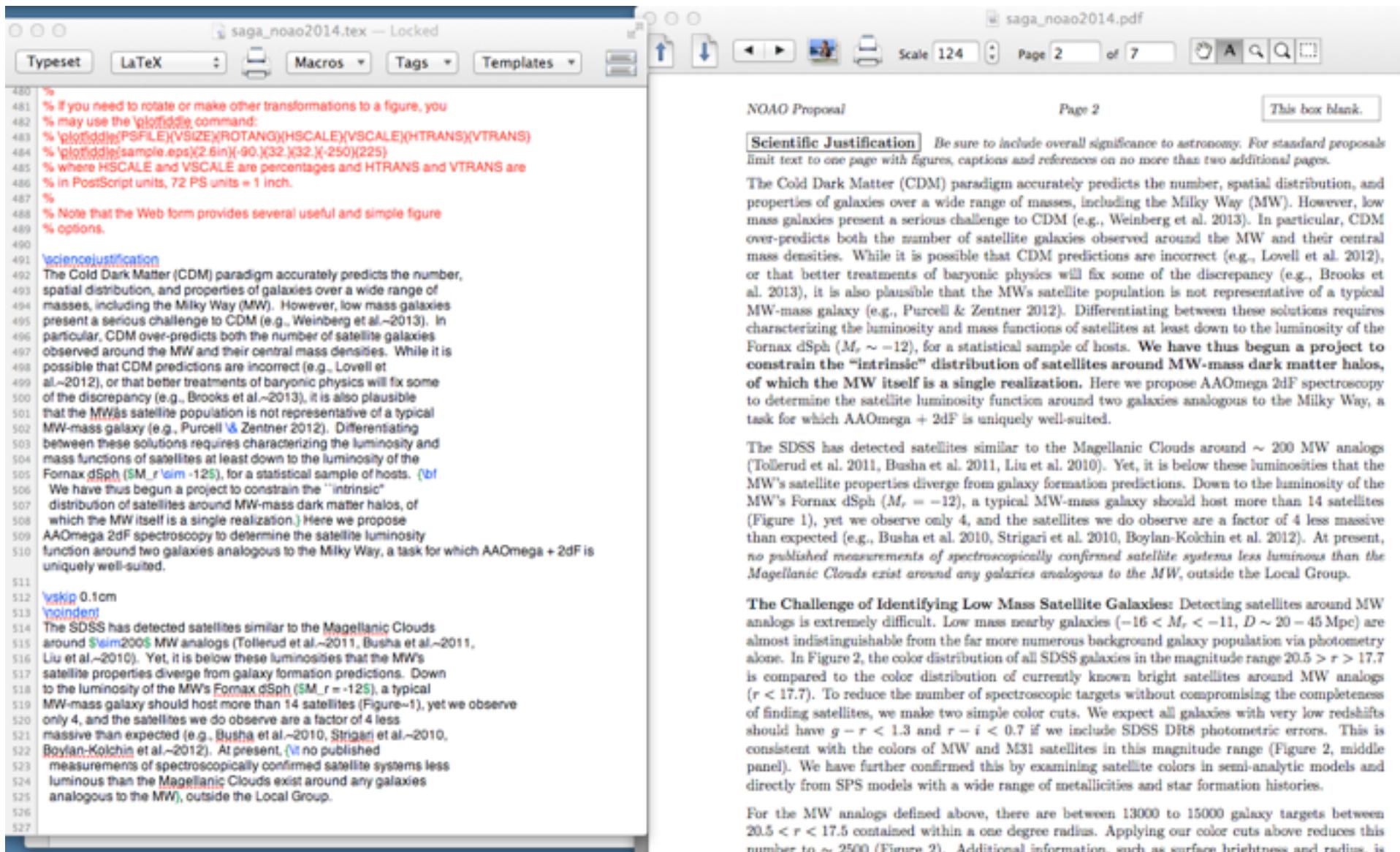
Broader Impacts: This provided partial postdoctoral support for L. Strigari (now an assistant professor at Texas A \& M) \& Y. Lu and a Stanford graduate student, and has led to nine publications. The PI gave public talks highlighting results from this funding. Our group also produced movies highlighting 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 extended 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.

The screenshot shows the Overleaf LaTeX editor interface. The top navigation bar includes links for PROJECT, HISTORY & REVISIONS, SHARE, PDF, JOURNALS & SERVICES, and user Marla Geha. The main workspace displays LaTeX code, a preview of the document, and journal submission details.

Code Preview:

```
510 affecting completeness at low redshift.
511 \label{fig_redshift}
512 \end{figure}
513 \subsubsection{Improving Efficiency: ugri and Machine Learning Algorithms}\label{ssec_ugri}
514
515
516 \subsubsection{The above $gris$ cuts reduce the total number of candidate
517 satellites which require spectroscopic follow-up without sacrificing
518 completeness. However, over 800 candidate satellite galaxies remain for each host galaxies,
519 precluding rapid completion of our 100 analog goal. We explore whether it is possible to further
520 increase the efficiency of finding satellites by introducing additional observed properties.
521
522 We have explored several additional observed properties.
523 For example in \autoref{fig_sb}, our satellites do not populate the high surface
524 brightness region. While we could use this property to cut galaxies,
525 we worry that this cut is more difficult to replicate in other surveys
526 due to differences in calculating surface brightness and is difficult to reproduce this quantity
527 in models. We find that including an additional cut in $u-r$ color, we are able to reduce the
528 number of candidate satellites significantly.
529
530 \begin{equation}
531 (u_o - g_o) + 2\sqrt{\sigma_u^2 + \sigma_g^2} < \\
532 1.5 ((g_o - r_o) - 2\sqrt{\sigma_g^2 + \sigma_r^2})
533 \end{equation}
534 \noindent
535 As shown in the green curve of \autoref{fig_redshift}, this additional
```

Journal Submission Details:

Debt of Galactic Analogs (SAGA): A SURVEY STRATEGY AND EARLY RESULTS
Marla Geha¹, Risa H. Wechsler², Yen-Yuan Mai³, Eric Tolbert^{1,4}, RAGNAR Werner, Ben Hontz, RICARDO MENDEZ, SEBASTIÁN MARÍNEZ, AND GÖTE OHLSSON¹

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²Kavli Institute for Particle Astrophysics and Cosmology & Department of Physics, Stanford University, Stanford, CA 94305, USA; SLAC National Accelerator Laboratory, Menlo Park, CA 94025, USA
³Department of Physics and Astronomy & Pittsburgh Particle Physics, Astrophysics, and Cosmology Center (PPAC), University of Pittsburgh, Pittsburgh, PA 15261, USA
⁴Space Telescope Science Institute, 3700 San Martin Dr., Baltimore, MD 21201, USA

ABSTRACT
We present survey strategy and initial results of the “Satellites Around Galactic Analogs” (SAGA) Survey. The SAGA survey goal is to constrain the distribution of satellite galaxies around 100 systems analogous to the Milky Way to the luminosity of the Leo II dwarf galaxy ($M_r \sim -12.3$). Here, we present luminosity functions for 8 Milky Way host galaxies between 20 to 40 kpc with nearly complete coverage for galaxies within the host virial radius down to ~ -20.75 within our low redshift selection criteria. We find a wide range, from 2 to 9 satellites, where we would expect 5 satellites around the Milky Way. It is difficult to explain these satellite numbers using basic abundance matching if simply extrapolated from higher luminosities. Unlike the satellites of the Milky Way, we find that the majority of satellites (26 of 28) are star forming. Our results also indicate that the Milky Way has a different satellite population than the hosts in our sample due to — potentially changing the physical interpretation of measurements based only on the Milky Way’s satellites.

Keywords: Galaxy: halo — Galaxy: structure

INTRODUCTION
Our home galaxy, the Milky Way, is the most well-studied galaxy in the Universe. From a cosmological and galaxy formation perspective, one of the most informative components of the Milky Way is its population of over two dozen dwarf galaxy satellites. However, the properties of these satellite galaxies do not agree with predictions of the simplest galaxy formation models in the CDM framework. The formation of this problem has had various incarnations, including the missing satellites problem and the too-big-to-fit problem (e.g. Boylan-Kolchin et al. 2011; Garrison-Kimmel et al. 2016a [add bibref]; Stadel 2016a [add bibref]). Stated simply, dark matter only simulations of modern CDM cosmologies predict a large number of dark matter subhaloes that either do not exist in the Milky Way, do not have bright satellite galaxies, or are not as dense as expected.

Although studies have considered the question of how typical the Milky Way is in terms of its bright satellite population, by studying the faintest detectable satellite galaxies around MW-analog in the SDSS spectroscopic survey (Lin et al. 2011; Guo et al. 2013; Tolbert et al. 2011; Seigar & Wechsler 2012 [add bibref]), the SDSS magnitude limit of $r = 17.7$ corresponds to satellites in the nearby Universe that are missing the Magellanic Clouds (two and four magnitudes fainter than the MW, $r = 2$ and 4). These studies find that our Galaxy is unusual, but not necessarily so, in its population of these bright satellites. The MW analog on average have only 0.3 satellites brighter than their luminosities, versus two for MW (Lin et al. 2010 [add bibref]). The distribution of these bright satellites is also significantly consistent with expectations from the more massive background galaxy population via SDSS photometry alone. In the absence of a large SDSS-like spectroscopic survey at least three magnitudes fainter, which will likely not exist for several years, we need a substantial improvement in methods to identify very low redshift galaxies. Through pilot work over the past few years, described below, we believe we have achieved the required improvement in efficiency without significant loss of completeness.

All distance dependent parameters in this paper are calculated using $h = 70 \text{ km s}^{-1} \text{ Mpc}^{-1}$. Magnitude and redshift are estimated using [SDSS DR12](#) [add bibref] as reported by SDSS DR12 and R converted to absolute zero using the [REDBAND](#) V, R, I software package (Blanton & Roweis 2007).

Figure Preview:

Introduction to LaTeX

To write equations in LaTeX, use math mode:

`$ E = mc^2 $`

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

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

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

$$E = mc^2$$

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

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

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

Greek Letters

```
alpha  
beta  
gamma  
delta  
epsilon  
zeta  
eta  
theta  
iota  
kappa  
lambda  
mu  
nu
```

Introduction to LaTeX

```
\begin{figure}[hbt]
\epsscale{1.00}
\plotone{figure3a.eps}
\caption{\small Distribution of known satellites for the Milky Way
analog NGC 6181 (\textcolor{blue}{middle panel}). The three brightest
satellites were found by SDSS, the two faintest satellites (\textcolor{blue}{left
left panels}) were found as part of our pilot observations with
WIYN HYDRA and MMT \textcolor{red}{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\textcolor{red}{kpc} (1 degree).}
\end{figure}
```

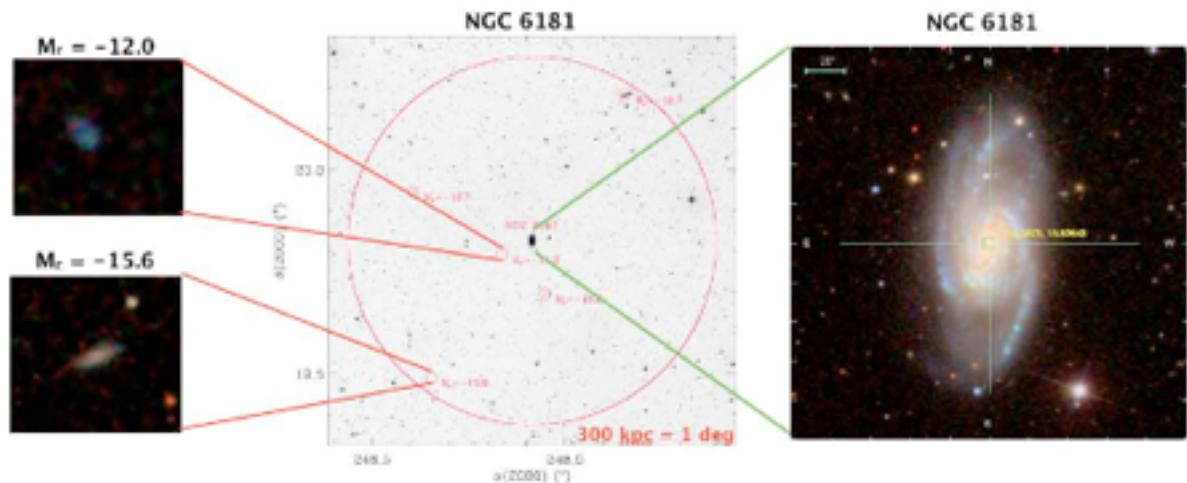


Figure 3: Distribution of known satellites for the Milky Way analog NGC 6181 (*middle panel*). The three brightest satellites were found by SDSS, the two faintest satellites (*left panels*) were found as part of our pilot observations with WIYN HYDRA and MMT Hectospec. The two faintest satellites fall 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, A., E. Greene, Jenny E. Geha, Marc
Affiliation:	AA(National Radio Astronomy Observatory, Charlottesville, VA 22903, Fellow.; aninev@nrao.edu), Alt(Department of Astrophysical Sciences, Princeton, NJ 08544, USA), AC(Department of Astronomy, Yale University, New Haven, CT 06520, USA)
Publication:	The Astrophysical Journal, Volume 775, Issue 2, article id. 116, 24 pp. (Homepage)
Publication Date:	10/2013
Origin:	ADS
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 ($10^{8.5} < M_{\text{star}} < 10^{9.5} M_{\odot}$) that exhibit optical signs of accreting massive black holes (BHs), increasing the number of known active galaxies in this size bin by more than an order of magnitude. Utilizing data from the Sloan Digital Sky Survey Data Release 7 from the NASA-Sloan Atlas, we have systematically selected for active BHs in $\sim 25,000$ emission stellar masses comparable to the Magellanic Clouds and redshifts $z < 0.055$. Using the narrow-line (NLL) diagnostic diagram, we find photoionization signatures of BH accretion in 136 galaxies, as well as broad H α emission. For these broad-line active galactic nucleus (AGN) candidates, we use standard virial techniques and find a range of $10^7 < M_{\text{BH}} < 10^9 M_{\odot}$, and a median of $M_{\text{BH}} = 10^8 M_{\odot}$. We also detect broad H α in 15 galaxies that have narrow-line ratios consistent with star-forming galaxies. Observations are required to determine if these are true type 1 AGN or if the broad H α is from star formation. The median absolute magnitude of the host galaxies in our active sample is $M_g = -18.1$ mag, which is lower than previous samples of AGN hosts with low-mass BHs. This work constrains the smallest galaxies that host active BHs, with implications for BH feedback in low-mass galaxies and the origin of the first supermassive black holes.

[BibTeX entry for this abstract](#) [Preferred format for this abstract \(use Preferences\)](#)



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 remarkable thing”

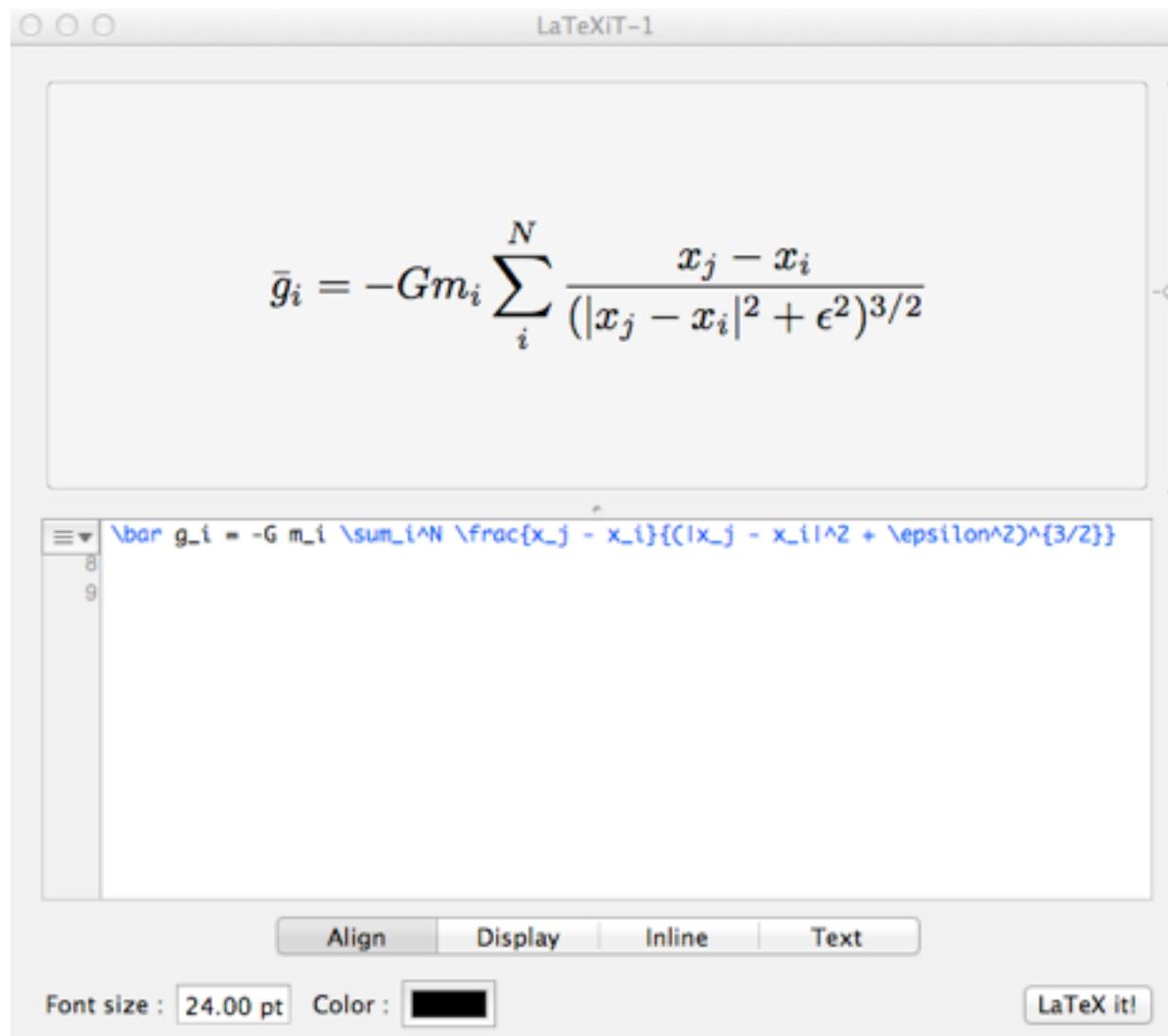
3. When compiles this text will appear as “As shown in this remarkable paper (Reines et al. 2013)”
or “Renes et al. (2013) shown this remarkable thing”

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

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.

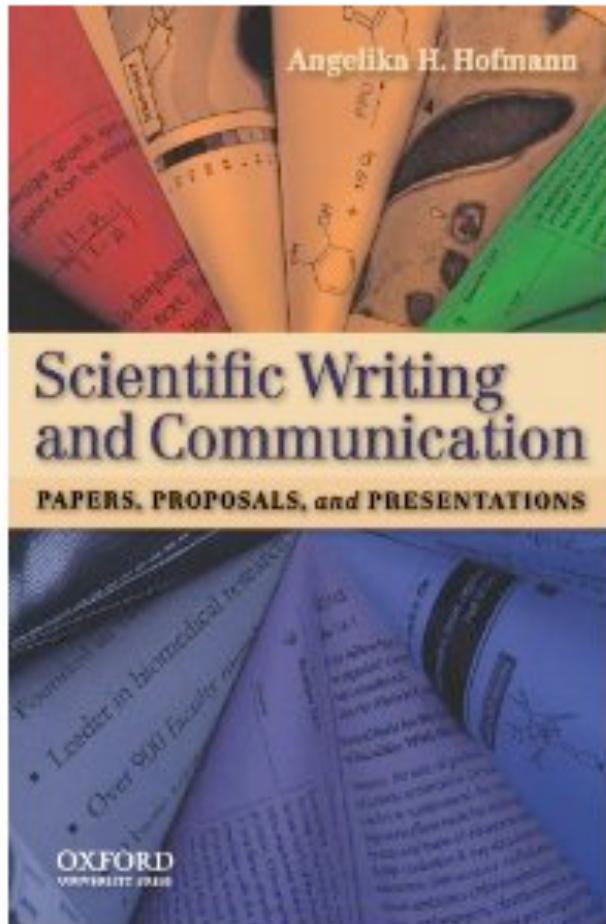
Scientific and technical writing can almost never be 'general purpose'; it must be written for a specific audience. For the kinds of writing addressed here, that audience will generally be the community of ecologists who read a particular journal or study a particular subject. This community is represented 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 slip 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 its final polish.

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

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

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2. First impressions count!

Research Statement: The Hierarchical Evolution of Dwarf Galaxies

My research addresses forefront problems in our understanding of the formation and evolution of galaxies through detailed numerical and observational studies of their basic building blocks, dwarf galaxies. The properties of galaxies today depend on the chemical and mass evolution of the objects they cannibalize. However, little is known about hierarchical assembly at low mass scales. My proposed research program will quantify the frequency at which dwarf galaxies interact with each other, both observationally and theoretically, and establish the contribution of such interactions to their star formation histories (SFHs) and baryon cycle using deep multi-wavelength observations of identified dwarf pairs. As such, this research program will result in testable models and establish close links between observations and theory.

1. Introduction

In the concordance Λ cold dark matter (CDM) theory, galaxies are expected to build up their mass by accreting smaller systems. Self-similarity dictates that this process should occur at all mass scales and thus interactions and mergers between low-mass galaxies must occur today and were necessarily a frequent occurrence in the early universe. Indeed, many local starbursting blue compact dwarf galaxies are believed to be the product of dwarf mergers (Lelli et al. 2012a). Despite being the most common class of galaxy (Binggeli et al. 1988), the interaction frequency between dwarf galaxies has never been systematically studied or quantified, largely because of surface brightness limitations and mass resolution limits in cosmological simulations. *I propose to carry out a comprehensive program utilizing both deep multi-wavelength observations of targeted dwarf galaxy pairs in the Local Volume and state-of-the-art cosmological simulations with high mass resolution in order to quantify the role of hierarchical mass assembly in the evolution of dwarf galaxies.*

Specifically, this program will establish the frequency with which dwarf galaxies interact with each other in underdense environments today, both theoretically and observationally (§2), and quantify the impact of such interactions on their star formation rates (SFRs; §3) and on the supply and removal of gas from these low mass systems (Baryon Cycle; §4). Comparisons of the observed dwarf-dwarf interaction frequency with cosmological expectations present a novel test of Λ CDM theory and a new direction for near-field cosmology.

In the context of hierarchical mass assembly, dwarf galaxies are often referred to as the “building blocks” of galaxies like our Milky Way (MW). As such, the chemical evolution and gas budget of dwarfs are of critical importance to understanding the current stellar populations and SFHs of the massive galaxies they form. Studies of the satellites in our Local Group have provided insights into the processes that control the evolution of these building blocks after accretion by a massive host, such as ram pressure/tidal stripping, strangulation and harassment (Moore et al. 1998; Mayer et al. 2006; Karanatzidis et al. 2011). Together these processes can explain the distance-morphology relationship exhibited by the satellites of the MW, wherein gas poor, non-star forming dwarf spheroidals (dSphs) are located at small Galactocentric radii (van den Bergh 2006). However, little is known about the evolution of dwarf galaxies prior to accretion; e.g., the nature of SF in such low-metallicity galaxies (Walter et al. 2011) and how they lose/accrete gas in underdense regions is unknown (but see studies of the Magellanic Clouds: Besla et al. 2010; 2012; and of interacting dwarfs in low mass groups: D’Onghia, Besla et al. 2010).

In particular, studies reaching outside the Local Group find that dwarfs further than 1.5 Mpc from a massive galaxy are all readily forming stars (Geha et al. 2012); quenching is not observed in low mass galaxies in the field. Thus, *the processes that govern the evolution of the dwarf satellites of the MW do not control the evolution of dwarf galaxies prior to accretion.*

Ultimately I aim to extrapolate the local dwarf interaction rate to higher redshift, directly probing the hierarchical evolution of the true building blocks of galaxies like our MW. *Without understanding the processes that shape the evolution of dwarf galaxies at early times, including their own hierarchical assembly, we cannot hope to understand how the properties of larger galaxies (stellar populations; metallicity; gas supply; SFHs) evolve over cosmic time.*

2. The Interaction Frequency of Dwarfs in Underdense Environments

Although examples of dwarf pairs are readily available (e.g. the Magellanic Clouds, Antennae, NGC 3664/A, etc.) the interaction rate of dwarfs in the field has never been quantified. With the introduction of large redshift surveys (e.g. SDSS) and high mass resolution simulations of cosmological volumes (e.g. the new Illustris simulation; Vogelsberger et al. in prep) we can finally probe the interaction rate between dwarf galaxies systematically, and directly challenge theoretical expectations of hierarchical galaxy formation with observations at the low mass end. The following questions will be addressed by this study:

1

COLLABORATIVE RESEARCH:

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

1 Science Motivation

Our home galaxy, the Milky Way, is in many respects the most well-studied galaxy in the Universe. One of the most cosmologically informative components of the Milky Way is its population of over two dozen dwarf galaxy satellites. A wide variety of precise measurements of the dark and luminous matter distribution exist for the Milky Way satellites that are not possible in more distant systems (e.g. Walker et al., 2007; Simon & Geha, 2007; Brown et al., 2012). However, this population constitutes a small, and perhaps biased, sample from which it is difficult to extrapolate generic properties. Do galaxies with similar luminosity, morphology, and mass as the Milky Way harbor a similar population of satellites? To apply our detailed knowledge of the Milky Way satellites to the broader questions of galaxy formation and dark matter properties requires an improved understanding of the Milky Way satellite population in a cosmological context.

Thus, to better quantify the MW in a cosmological context, the first of three proposal objectives is to measure the luminosity function of satellites around a sample of approximately 100 galaxies similar to the MW. We will additionally measure the mass function of satellites for a subset of these systems. As motivated below, we will focus on galaxies with luminosities equal to or brighter than the Fornax dSph ($M_V = -13.2, L_V = 10^7 L_\odot$).

Several recent studies have considered the question of how typical the MW is in terms of its very bright satellite population by studying the faintest detectable satellite galaxies around MW-like galaxies in the Sloan Digital Sky Survey (SDSS). These are satellites similar to the Large and Small Magellanic Clouds, which are two and four magnitudes fainter than the MW itself (we define this magnitude difference between host and satellite as Δm). Generally, these results indicate that MW luminosity-galaxies on average have only ~ 0.3 satellites with $\Delta m < 4$, and are remarkably consistent with simulations (Liu et al., 2011; Guo et al., 2011; Tollerud et al., 2011; Busha et al., 2011b). These studies find that, in terms of the population of very bright satellites, our Galaxy is unique, but probably not uncomfortably so.

Starting with the basic assumption that luminosity correlates with mass, theoretical models for the satellite luminosity function typically run into one of two problems. Using modern simulations to predict the dark matter subhalo distribution around the MW, most models are only able to reproduce the observed satellite luminosity function if Fornax-like dSphs ($\Delta m = 8$) reside in halos with maximum circular velocity $v_{max} \sim 40 - 50 \text{ km s}^{-1}$ (e.g., Busha et al., 2010). This is roughly a factor of two larger than the strongly constrained $v_{max} \sim 20 \text{ km s}^{-1}$ for Fornax (Strigari et al., 2010a). If we instead simply count the number of simulated objects more massive than $v_{max} = 20 \text{ km s}^{-1}$, we predict that, on average, there should be $\sim 25 - 35$ satellites that are more massive than Fornax (Springel et al., 2008; Diemand et al., 2008), whereas we observe only 3 objects that are more luminous than Fornax. Thus, in order to form a consistent picture, the bulk of these subhaloes must be entirely devoid of detectable numbers of stars (Boylan-Kolchin et al., 2011). However, these conclusions are based on *fewer than 10 simulated MW systems*. Our second objective is to produce a statistical sample of MW-analog systems with sufficient numerical resolution to study satellites with circular velocities $v_{max} > 20 \text{ km s}^{-1}$. In order to compare with the Milky Way as well with our observed sample of distant local groups, we will select three independent samples of 100 halos each: luminosity-selected systems (with criteria identical to our observational

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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 Lyras, BHB stars, etc.) is selected^{2,125}, 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, Λ CDM-based numerical simulations by Co+I Johnston¹⁴ predict that the outer stellar halo should be lumpy, flattened, and coured 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, BHBs, RR Lyras 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 challenged¹²¹.

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 NW, 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 halo⁷. 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 ([α] — 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 Λ CDM simulations, but cannot provide a precision measurement and provide insufficient constraints¹²⁰. And while the inner halo of M31 does contain abundant evidence of accretion through substructure, including the spectacular GSS¹¹, 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^{77,106,120} 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 $v_{\text{max}} = 20 \text{ km s}^{-1}$, 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 reionization.
- **Is the Milky Way rare in its population of bright dwarf spheroidals?** An observational solution to the Fornax Problem is the suggestion that the MW satellites are not representative of a typical MW-mass galaxy, due to a rare downward fluctuation in its population of bright satellites. Understanding how the satellite population of the MW compares to similar galaxies is a key goal of this work
- **Modification of the subhalo mass function:** Alternatively, the dark matter satellite population predicted by Λ CDM simulations may not be representative of our MW or similar systems. There are two categories of such solutions. First, modern dark matter simulations of substructure around MW-like galaxies do not include all of the necessary baryonic physics effects at the necessary numerical resolution. Numerical simulations are beginning to incorporate realistic baryonic effects, though it is too early to cleanly interpret the results (Wadepuhl & Springel, 2011; Parry et al., 2011). Alternatively, the lack of observed subhalos may point to modifications of the standard cosmological model, or to the properties of particle dark matter. For example, Warm Dark Matter decreases the number of dense satellites and may allow for a more direct mapping between the brightest satellites and the most massive substructures (Lovell et al., 2011).

The goal of this project is to understand the satellite population of the MW down to Fornax dSph-like satellites with $\Delta m = 8$. We will observationally determine the satellite luminosity function to this scale for 100 MW-analog galaxies, and obtain in parallel 300 simulated MW-like galaxies with sufficient numerical resolution to resolve satellites with $v_{\text{max}} > 20 \text{ km s}^{-1}$. We will then compare in detail these two statistically significant samples to differentiate between currently proposed models of galaxy formation at the smallest scales.

2 Proposal Objectives

This proposal describes a project to fully characterize, both observationally and theoretically, the satellite system of a typical MW-mass galaxy down to the scale of the Fornax dSph, which is eight magnitudes dimmer than the MW, or $\Delta m = 8$. Three directions are required to achieve this goal:

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 ($10^{3-4}L_{\odot}$) 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 $r \sim 23$, 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. Diametrical dE measurements such as orbital and other galactic basis kinematics

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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, Λ CDM-based numerical simulations by Co+I Johnston¹⁴ predict that the outer stellar halo should be lumpy, flattened, and cusped 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 challenged¹³¹.

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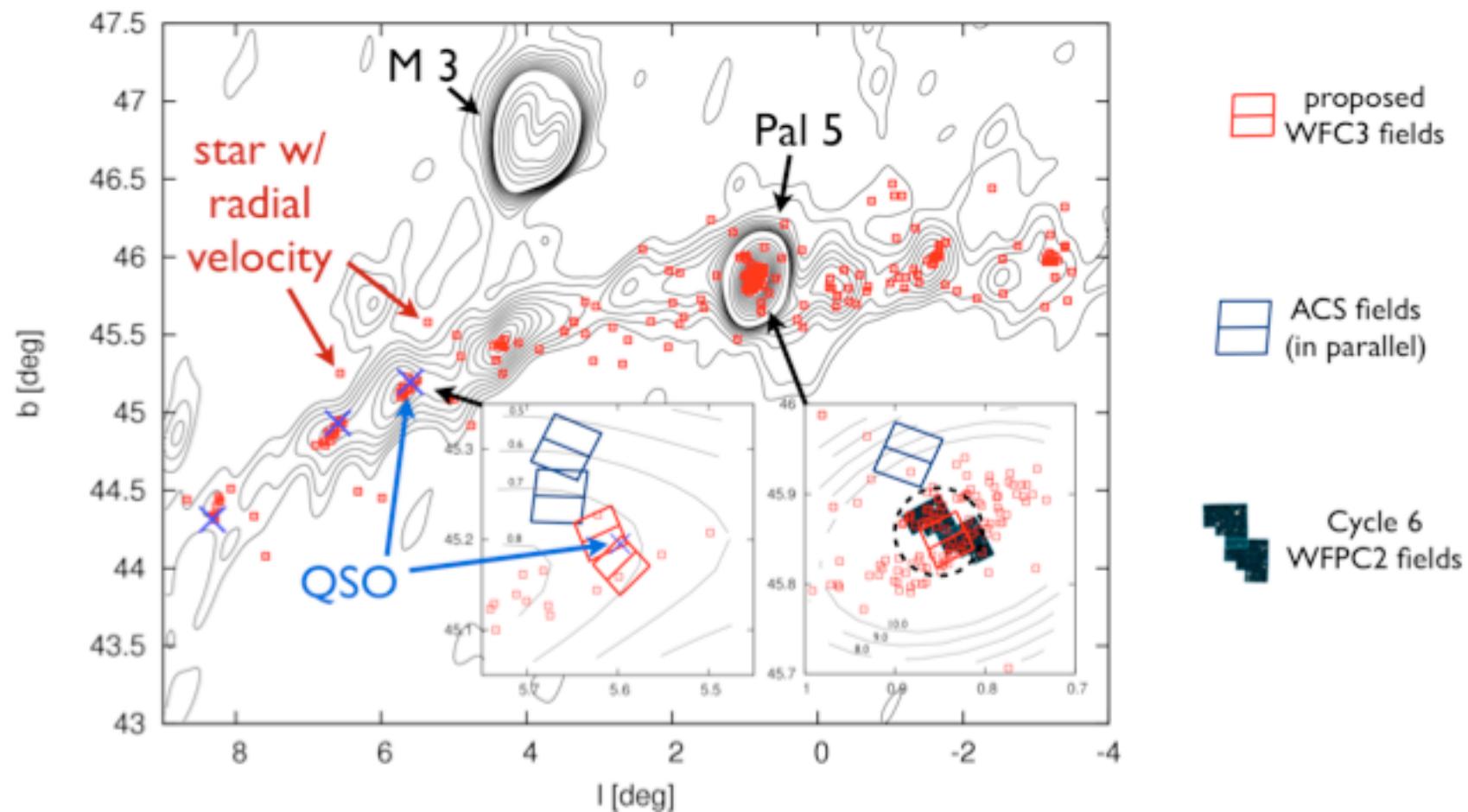
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6. Captions should not merely name a table or figure, they should explain how to read it.

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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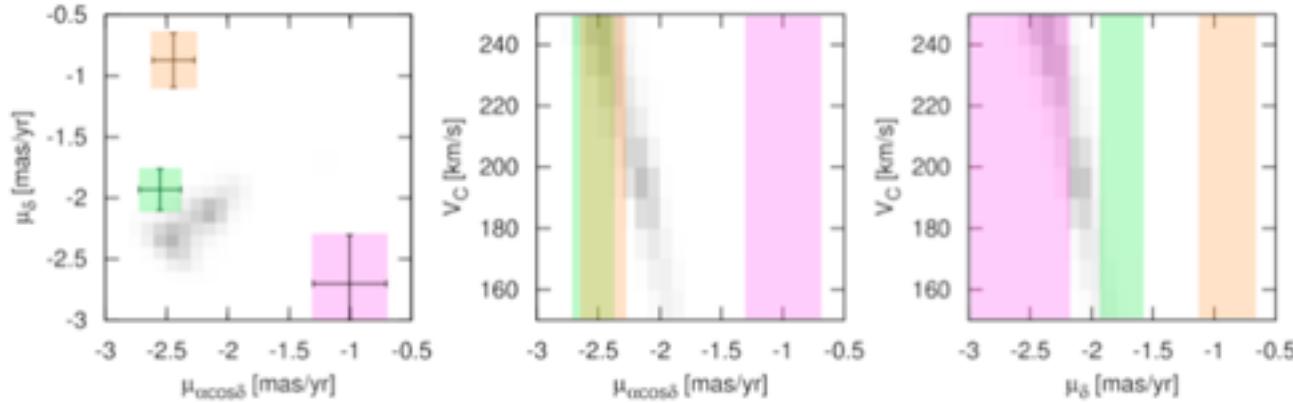


Figure 2: *Left:* Expected PM from our TT modeling. The grey scale gives goodness-of-fit values of our TT models to the published observational data, where dark grey corresponds to model parameters which reproduce the observational data well. Models with a PM of ≈ 2 and ≈ 2.5 mas/yr in both coordinates 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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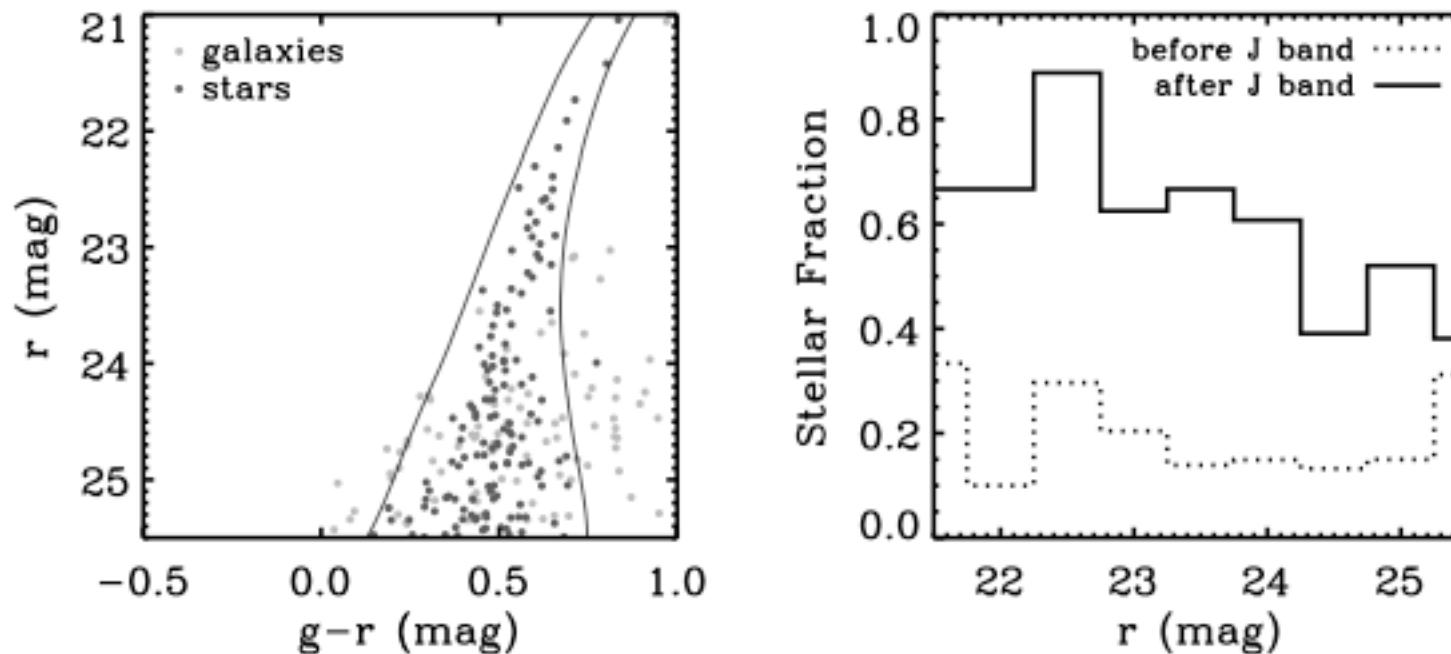


Figure 3: Plotted on the left is the $g - r$ CMD presented in Figure 2, after first selecting objects within the isochrones plotted in the $g - J$ CMD. Since many of the galaxies do not lie on the stellar locus (and many are fainter than $J = 24$), the number of galaxy counts is severely reduced and 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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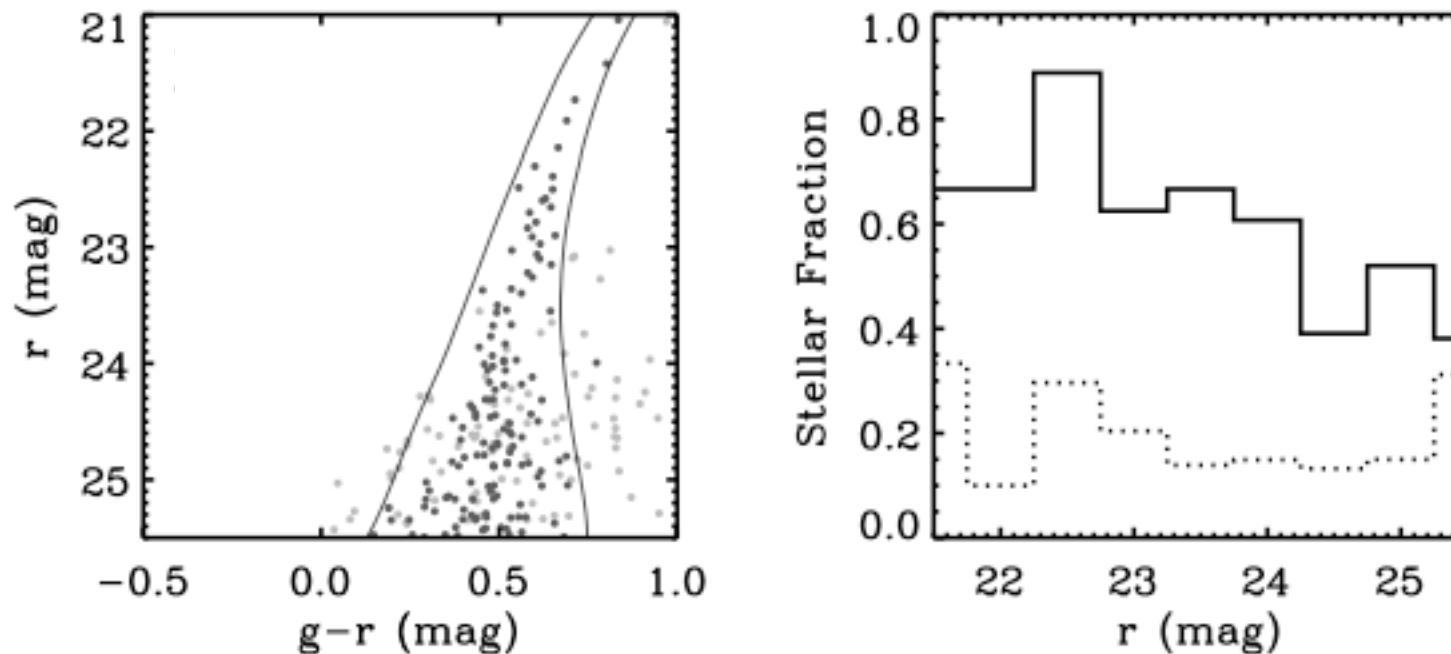


Figure 3: Plotted on the left is the $g - r$ CMD presented in Figure 2, after first selecting objects within the isochrones plotted in the $g - J$ CMD. Since many of the galaxies do not lie on the stellar locus (and many are fainter than $J = 24$), the number of galaxy counts is severely reduced and 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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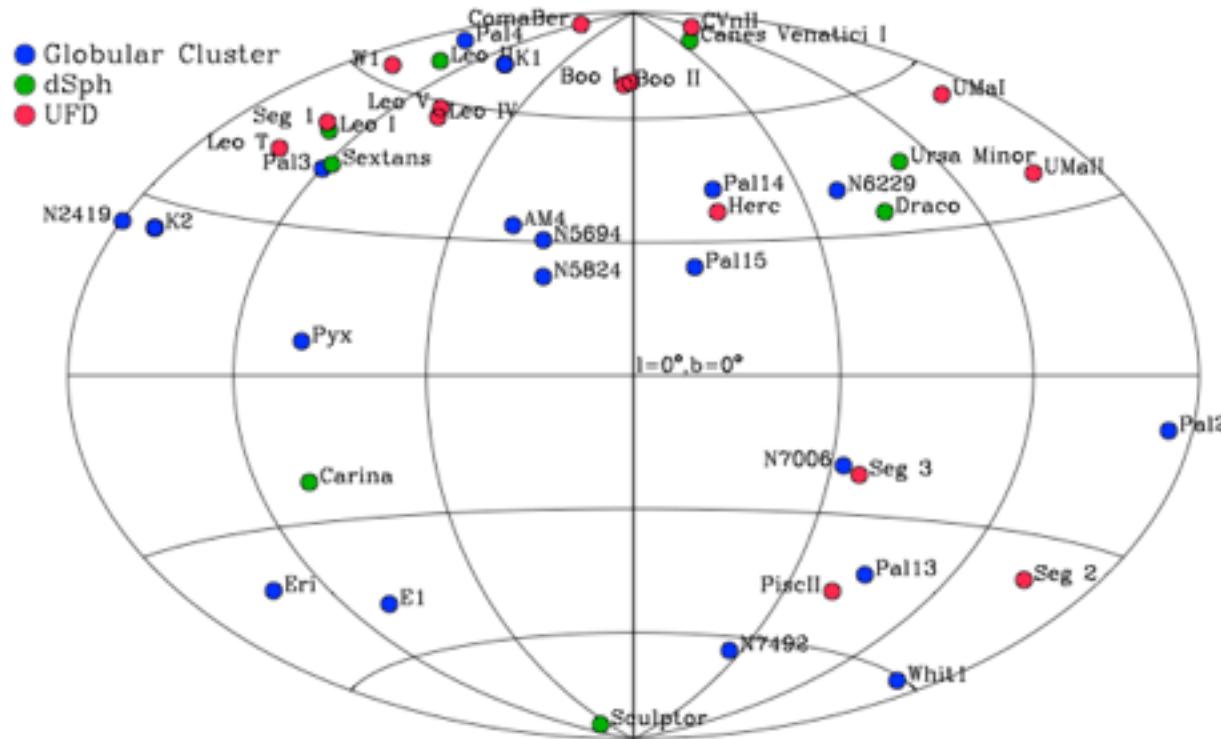


Figure 1: Locations of all known globular clusters (blue triangles), dSphs (green circles) and ultra-faint galaxies (red circles) known around the Milky Way. The larger number of objects at high galactic longitude is due to discoveries in the SDSS. Our Megacam survey program will be the first deep, wide-field,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



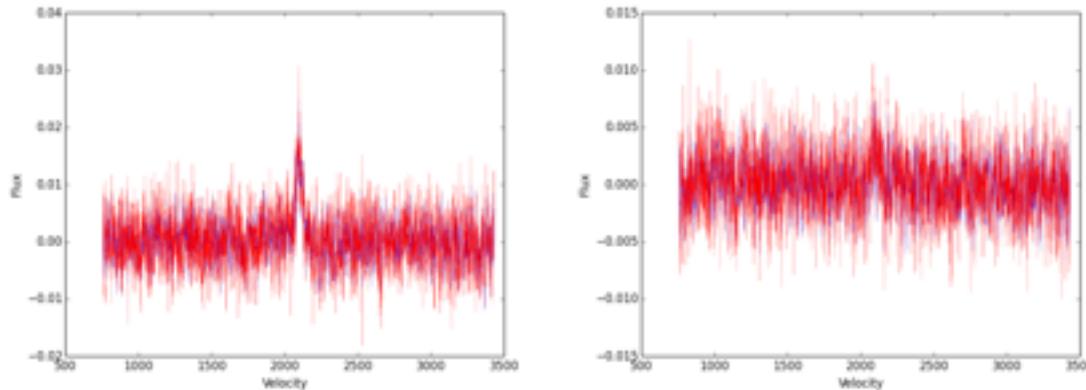
An increase in temperature occurred.



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.

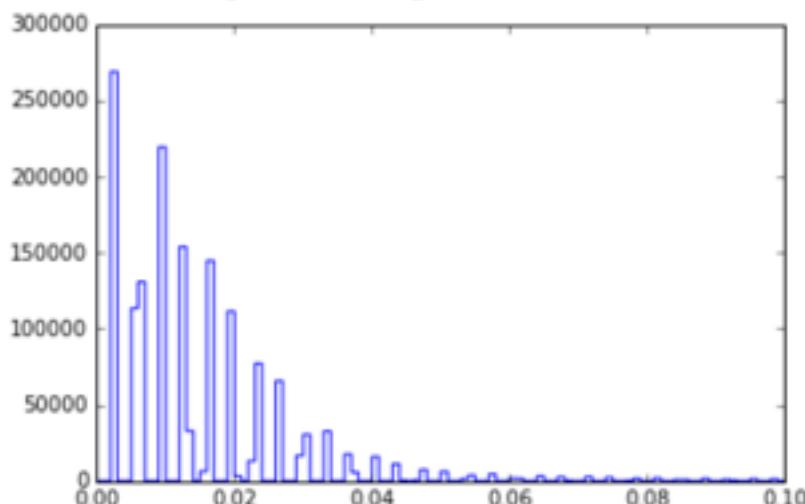


good: plots are labeled

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

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.

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?

MARRIAGE vs. The Ph.D.



Marriage



Ph.D.

Typical Length:	7.5 years	7 years
Begins with:	A proposal	A thesis proposal
Culminates in a ceremony where you walk down an aisle dressed in a gown:	✓	✓
Usually entered into by:	Foolish young people in love	Foolish young people without a job
50% end in:	Bitter divorce	Bitter remorse
Involves exchange of:	Vows	Know-how
Until death do you part?	If you're lucky	If you're lazy

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