HST GO Proposal Structure
Components

• Abstract
• Science Justification
• Technical Justification
  – GO: Observational Strategy
  – AR: Analysis Plan & Management Plan
• 2 pages for figures/references
• Past HST Usage
GO Abstract Recipe

**Set the stage** & be concise !!!!

- Start with one or two facts
- Explain why these facts are important
- State your goal
- Introduce the problem
- Explain why HST obs. will solve it (strategy/instrument)
- Explain the broader implications of your results

[ Order of any of the above can be interchanged,
Some like to start with the goal. Some like to start with the problem]
Example GO Program: Proper Motion Field Along the Magellanic Bridge

Abstract

Our HST proper motion (PM) measurements of the LMC and SMC have revolutionized our understanding of the Magellanic System, and have spurred new research on its use as a cosmological probe of galaxy formation. The PMs imply that the Magellanic Clouds are likely on their first infall towards the Milky Way (MW). The disturbed nature of the Magellanic System is therefore likely due to the LMC-SMC interaction, and not to the MW influence. This has emphasized the importance of dwarf galaxy interactions for galaxy evolution. The Clouds are connected by a complex of gas and stars called the Magellanic Bridge. We propose to map the stellar PM field of the Bridge, similar to our prior HST mapping of the LMC PM rotation field. Our state-of-the-art N-body simulations show that the PM field will tightly constrain the impact parameter of LMC-SMC orbit at its last pericenter 100-300 Myr ago, which is the main uncertainty in our understanding of the LMC/SMC interaction history. This will test whether the tidal debris between the galaxies is due to a recent direct-hit collision. It will also test models in which the tidal debris is responsible for the observed microlensing events.

We will observe once 3 fields for which first-epoch archival data already exists, and observe twice 5 other fields over a 2-cycle time baseline. With the established data reduction techniques of our successful HSTPROMO collaboration, this will yield PM accuracies of 10-25 km/s per field, well below the 130 km/s velocity difference between the Clouds. This will yield the best constraints to date on the LMC/SMC interaction, and will further test the importance of dwarf-dwarf interactions for galaxy evolution.
Part 1: Science Justification

- GO Small Proposals: 3 Page Science [8 total]
- GO Medium Proposals: 4 Page Science [9 total]
- GO Large Proposals: 6 Page Science [11 total]

- Theory & AR: 3 Page Science [8 total]
- AR Legacy: 6 Page Science [11 total]

- No limits on figures, but total page count matters
- 12 pt font
Science Justification: Section 1

The Big Picture

• Use descriptive headings (not “intro”/ “backgrd”)
• 1-3 paragraphs:
  • Explain/Justify “the Facts” stated in abstract
  • Explain the importance of “the Facts”
  • Team expertise (why are *you* proposing) & Role of HST in establishing facts.
  • Introduce the “Problem”
• Last paragraph (1-2): (to be expanded upon in the remainder of the proposal)
  – State the GOAL & the observation
  – State that they will fix “the problem” by doing *blah*
  – Big picture statement to end it off
Introduction: The field of astrometry is poised to produce fundamental advances in our understanding of the local Universe in the coming decade. The remarkable stability and resolution of ACS and WFC3 position HST to play a leading role, enabling precise measurements of proper motions (PMs) that complete the full 6-dimensional orbital phase space of nearby galaxies. HST astrometry measured by our collaboration already has led to breakthroughs such as (1) determining the orbit of the Large and Small Magellanic Clouds (LMC and SMC) (Kallivayalil et al., 2013), (2) detecting internal rotation in the LMC (van der Marel & Kallivayalil, 2014), (3) measuring the tangential motion of the distant satellite Leo I, as well as M31 (Sohn et al., 2012, 2013), and (4) constraining the presence of intermediate-mass black holes in globular clusters (Anderson & van der Marel, 2010). Simultaneously, the satellite dwarf galaxies around the MW have emerged as key testbeds for ΛCDM, the epoch of reionization, and the physics of galaxy formation. However, progress in all of these areas is significantly limited by the lack of comprehensive, unbiased, and robust PM measurements. Of the 51 known dwarf galaxies within ≈ 400 kpc, only 10 (20%) have well-measured PMs, and these form a biased sample, being relatively nearby and/or massive (“classical”) dwarfs (Figure 2). Furthermore, 32 (two-thirds) do not have good ACS/WFC3 imaging for even the first epoch of a PM measurement, even though HST can readily measure them.
1 Cosmological Importance of the Magellanic System

Most of our understanding of galaxy dynamics is based on studies of line-of-sight velocities. Proper motions (PMs) are required to determine 3D velocities. Our HSTPROMO collaboration (see “Past HST Usage” Section) has been successfully determining PMs throughout the Local Group (e.g., van der Marel et al. 2012). Our 2002–2009 measurements of the Large and Small Magellanic Clouds (LMC/SMC) revealed that they move faster with respect to the Milky Way (MW) than previously believed (Kallivayalil et al. 2006a,b, 2013). This has revolutionized our understanding of the Magellanic System, and spurred much new research on the use of the LMC/SMC as cosmological probes of galaxy formation and evolution.

We showed that the PM measurements imply that, instead of being long term companions, the Magellanic Clouds are likely on their first infall towards the MW (Besla et al. 2007). Such late infall is not unexpected in light of cosmological simulations (Boylan-Kolchin, Besla & Hernquist 2011). This confirms that the hierarchical build-up of galaxies like the MW continues to the present day, and is directly affected by galaxies like the LMC/SMC. The Clouds are connected by the Magellanic Bridge, a complex of gas and stars that connect the Clouds (see Fig. 1), and they lead the Magellanic Stream, a long tail of hydrogen gas that spans 150° across the sky. This gaseous debris will eventually feed the MW’s gaseous halo, so the formation mechanism of such structures is an important mode of gas supply to our MW.

Much debate has ensued about the formation of the Stream in light of our PM results (e.g., Diaz & Bekki 2012; Peebles & Tully 2013). Traditional models of the Stream have relied on tidal or ram pressure forces from the MW to create the Stream. But these forces are negligible if the Clouds have spent most of their time at large distances from the MW. In Besla et al. (2010) we showed that instead the Magellanic Stream and Bridge may be due entirely to interactions between LMC and SMC. This has put focus on interactions between dwarf galaxies as an important component of galaxy evolution. Evidence for such interactions has also been found in other Magellanic irregulars, like NGC 4449 (Martinez-Delgado et al. 2012). In Besla et al. (2012) we argued that dwarf-dwarf interactions may be the primary driver for the formation of the entire class of Magellanic Irregulars.
Through this Treasury program, we propose a comprehensive survey to provide robust imaging for optimal first-epoch proper-motion measurements for all known dwarf galaxies out to 420 kpc, encompassing the MW’s full halo profile out to its virial radius. Specifically, we will target the 32 known dwarf galaxies that currently do not have adequate ACS/WFC3 imaging. Here, we propose for exclusively first-epoch imaging, to provide a solid foundation to be followed up with second-epoch baselines by HST and JWST over the next 4 - 11+ years, to enable unprecedented proper-motion measurements.

Because we do not know how long HST will last beyond 2020, it is “now or never” to start such a PM survey that can be realized by HST. Even more excitingly, JWST will have similar resolution and capabilities for PM measurements as HST, so it can be used to leverage HST first-epoch data over an 11+ year baseline. Given the relatively short proposed lifetime of JWST, it is critical that HST establishes first-epoch baselines now, to leverage JWST’s full lifetime for optimal PM measurements. As we argue below, this will allow HST to do transformative science on many fronts, uniquely addressing critical issues related to galaxy formation, cosmic reionization, and the nature of dark matter.
The goal of the present proposal is to use HST to map the PM field over the extent of the Magellanic Bridge to better understand the LMC/SMC interaction history. These first PM measurements for stellar debris associated with the Magellanic System will be compared to our detailed N-body simulations, which will allow us to distinguish between different possible scenarios. Furthermore, stellar debris from the encounter has been proposed as the source of the microlensing events observed towards the LMC by the MACHO and OGLE collaborations (Besla et al. 2013). Such models depend sensitively on the tangential motions of the stellar debris, which we will directly constrain. Our study has cosmological importance for understanding the formation and evolution of both dwarf and massive galaxies.

Goal/Proposal – to be expanded upon

The plan to use HST to fix the Problems – to be expanded upon

Broader Impact - to be expanded upon
Section 1 sets up 4 things to be expanded upon:

• Section 2: The Problem/Motivation
• Section 3: The Proposal/Target/Goal
• Section 4: Why the Target/Proposal solves the Problem
• Section 5: Broader Impacts
Science Justification: Section 2
The Problem & Motivation

• Explain “the problem” stated in the abstract
• MOTIVATION OF THE PROPOSAL
• SMALL programs: Identify “the key component” of “the problem” (be specific – well contained problem)
• Explain why “the key component” is crucial
Section 2. Bridge

The mass uncertainties allow many different past orbits of the SMC with respect to the LMC. The Clouds were definitely much closer to each other 100–300 Myr ago than their current ~ 20 kpc separation. However, the exact impact parameter at the last pericenter is not known. Allowed scenarios vary from a direct collision \( R_{\text{sep}} \lesssim 10 \text{ kpc} \) to a complete miss \( 10 \lesssim R_{\text{sep}} \lesssim 20 \text{ kpc} \) \cite{Kallivayalil2013}. The impact parameter is key for the proper explanation of a number of different issues, including the LMCs peculiar off-center bar, and the presence of tidal debris that might contribute to the observed micro-lensing optical depth.

In \cite{Besla2012} we compared \( N \)-body models with different impact parameter to the observed internal structure and kinematics of the LMC and SMC, but we found that those data do not have sufficient discriminatory power to uniquely determine the impact parameter.
Science Justification: Section 3
The Target & Plan
-- Feasibility of HST Obs.

• Why are you targeting what you are targeting
  – A figure can help here
• Why does your target solve the problem
• Why will HST be able to observe the target
  (point to existing data, or sensitivity limits)
Bridges between galaxies are hallmarks of galactic tidal encounters (Toomre & Toomre 1972). The Magellanic Bridge is therefore key for probing the LMC/SMC interaction. It is generally accepted that the Bridge formed during the last close approach, \( \sim 100–300 \) Myr ago, by material stripped from the SMC by LMC. As such, the Bridge properties depend critically on the distance between the Clouds at that time (Besla et al. 2012). Moreover, the Bridge contains stars in addition to gas, which makes it more amenable to study than the Stream, in which no stars have ever been detected. Gas is subject to both hydrodynamical forces and gravitational/tidal forces, which makes it more difficult to use as a probe of the interaction history.

Young stars are readily observable in the Magellanic Bridge (Irwin et al. 1990; Harris 2007). Young stellar objects (e.g., Sewilo et al. 2013) confirm that in situ star formation is occurring. Recently, Bagheri et al. (2013) used data and color information from the WISE and 2MASS surveys to identify older RGB and AGB stars (confirmed also by Noel et al. 2013) spread all across the Bridge area (see Fig. 2). While these IR surveys detect only a sparse distribution of the brightest giants, the much more numerous fainter main sequence population is clearly detected in deep HST pointings in the Bridge area (Fig. 3). This makes it possible to use HST to map the PM field of the Magellanic Bridge, similar to what we have done previously for the LMC (see Fig. 4). The older stars could in principle be part of an extended stellar halo associated with the SMC or LMC (Nidever et al. 2011), rather than tidal debris, but this something that can be directly assessed using PM data.
Figure 1 (left) HI map of the Magellanic System (Brüns et al. 2005). The boxed areas on the left and right are centered on the LMC and SMC, respectively, and indicate the regions for we have already mapped the PM field with HST (see e.g. Fig. 4). We propose to target the labeled fields to map for the first time the PM field of the Magellanic Bridge between the Clouds.
Science Justification: Section 4
The Target and “The Problem”

• Show that the observations will address ‘the problem’ -- a Figure can help here.
• *STATE* that it will solve the problem.
• Describe some bonus science
Why HST will solve the problem
Science Justification: Section 5
Big Picture Implications

• How does the observations help other science?
• Other uses for the data set (legacy value)
• Section 1: Explain the “Facts” and state “Goal”

• Section 2: The Problem (identify the key component of the problem)

• Section 3: Describe The Target
  For GO: Feasibility of HST observations (justify HST)
  For AR: What HST data sets are relevant

• Section 4: HST Observations of Target Solves the Problem
  For GO: describe the proposed observations briefly
  For AR: describe the analysis method briefly

• Section 5: Broader Implications
  For AR: indicate that new data products will advance the field