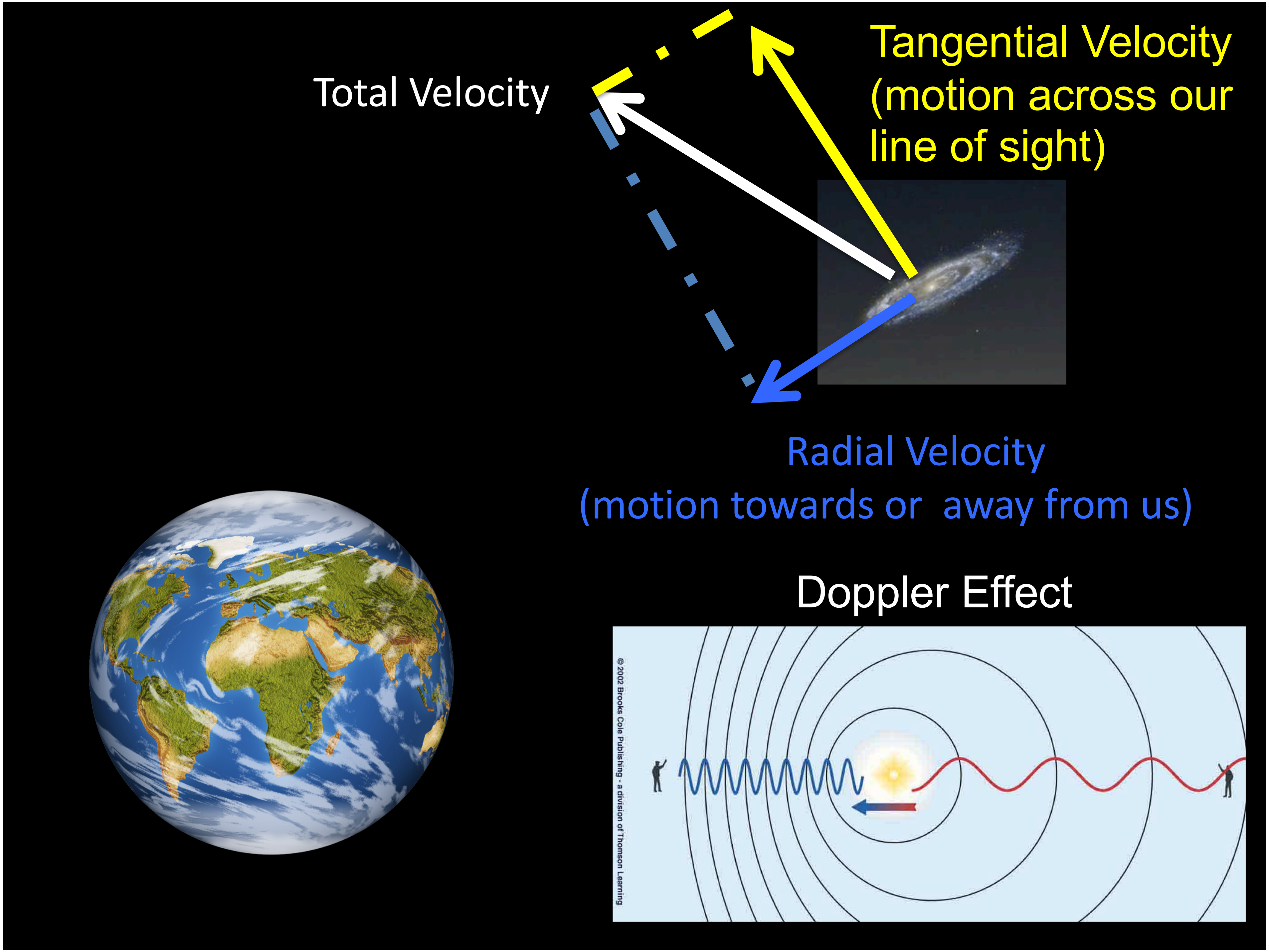
HST GO Proposal Structure


Total Velocity
Tangential Velocity
(motion across our
line of sight)
Radial Velocity
(motion towards or away from us)
Doppler Effect
© 2002 Brooks Cole Publishing - a division of Thomson Learning

Tangential Motion ← Proper Motion

The **proper motion** of an object is the measurement of its angular change in position on the sky over time.

<u>Barnard's Star:</u>

Highest proper motion of any star visible from the Earth.

True motion: 140 km/s!

Credit: Steve Quirk

HSTPROMO

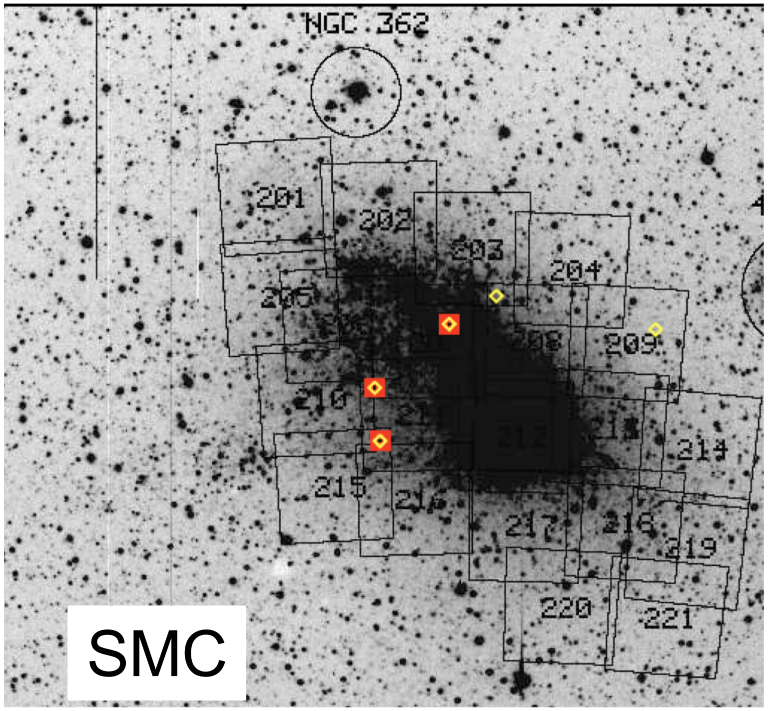
The Hubble Space Telescope Proper Motion Collaboration

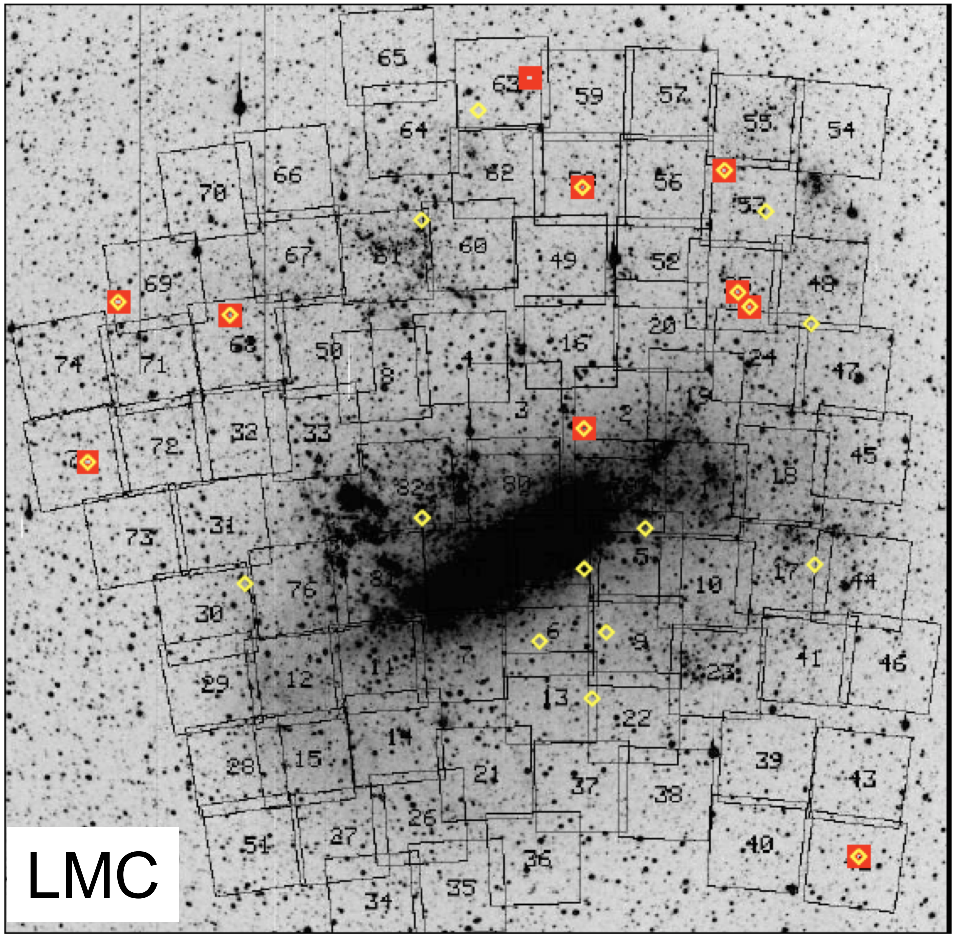
Need to measure changes in the motions of stars in a galaxy of ~ 30 μas/yr

→ measure a change of 0.006 pixels over 10 yrs!!!

~ The speed of human hair growth at the distance of the Moon

LMC/SMC Proper Motions





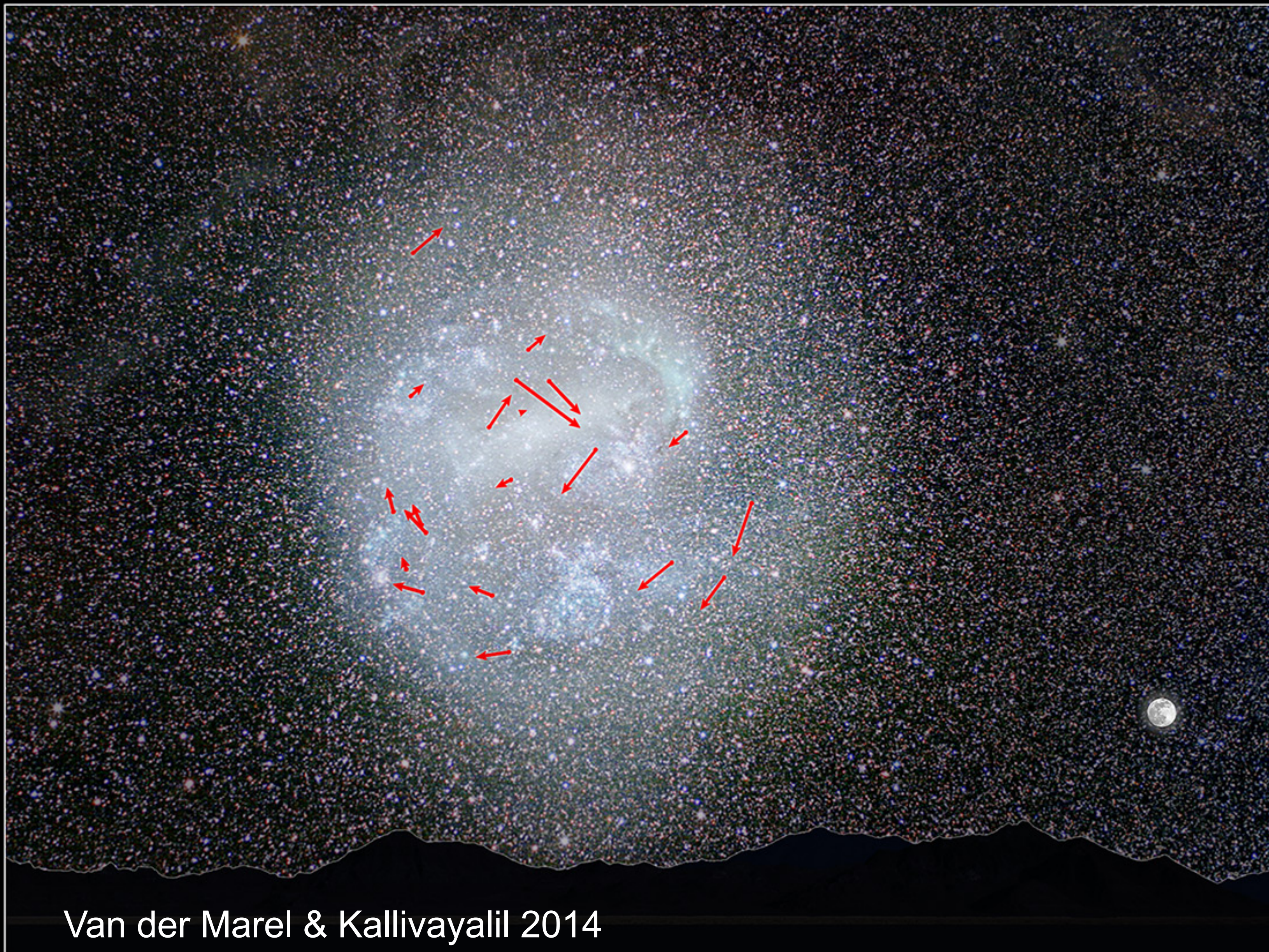
3rd Epoch WFC3: 7 yr baseline,
PM accuracy 20-50 μas/yr

V_{LMC} = 321 +/- 24 km/s
V_{SMC} = 217 +/- 26 km/s

(Kalllivayalil, van der Marel, Besla + 2013; New V_{LSR}, new Kinematic models)

HSTPROMO: The First Direct Proper Motion Measurement of M31

Sohn + 2012 (12 μas accuracy)



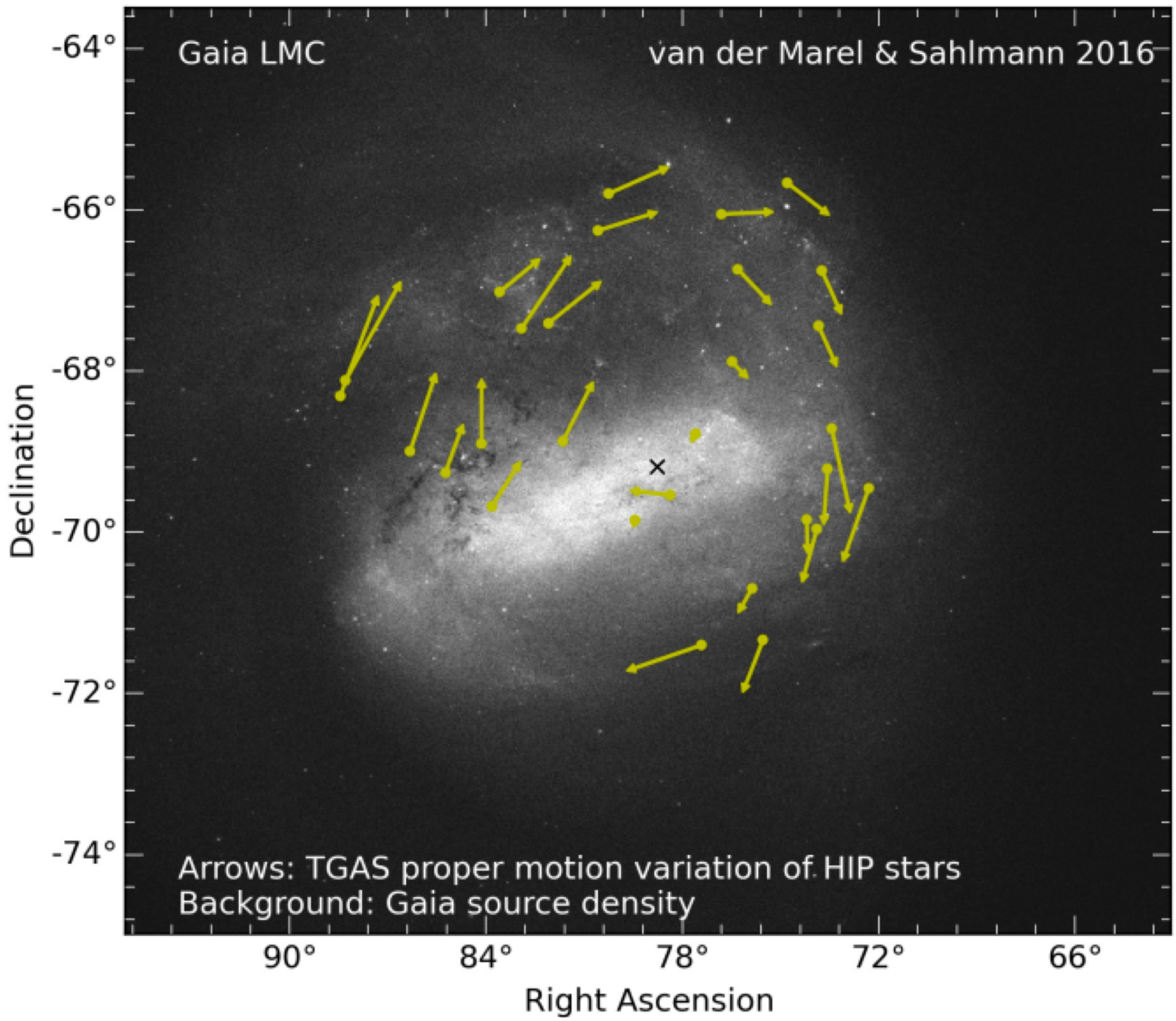
Hubble Measures Rotation of the Large Magellanic Cloud • Photo Illustration

NASA and ESA ▪ STScI-PRC14-11a

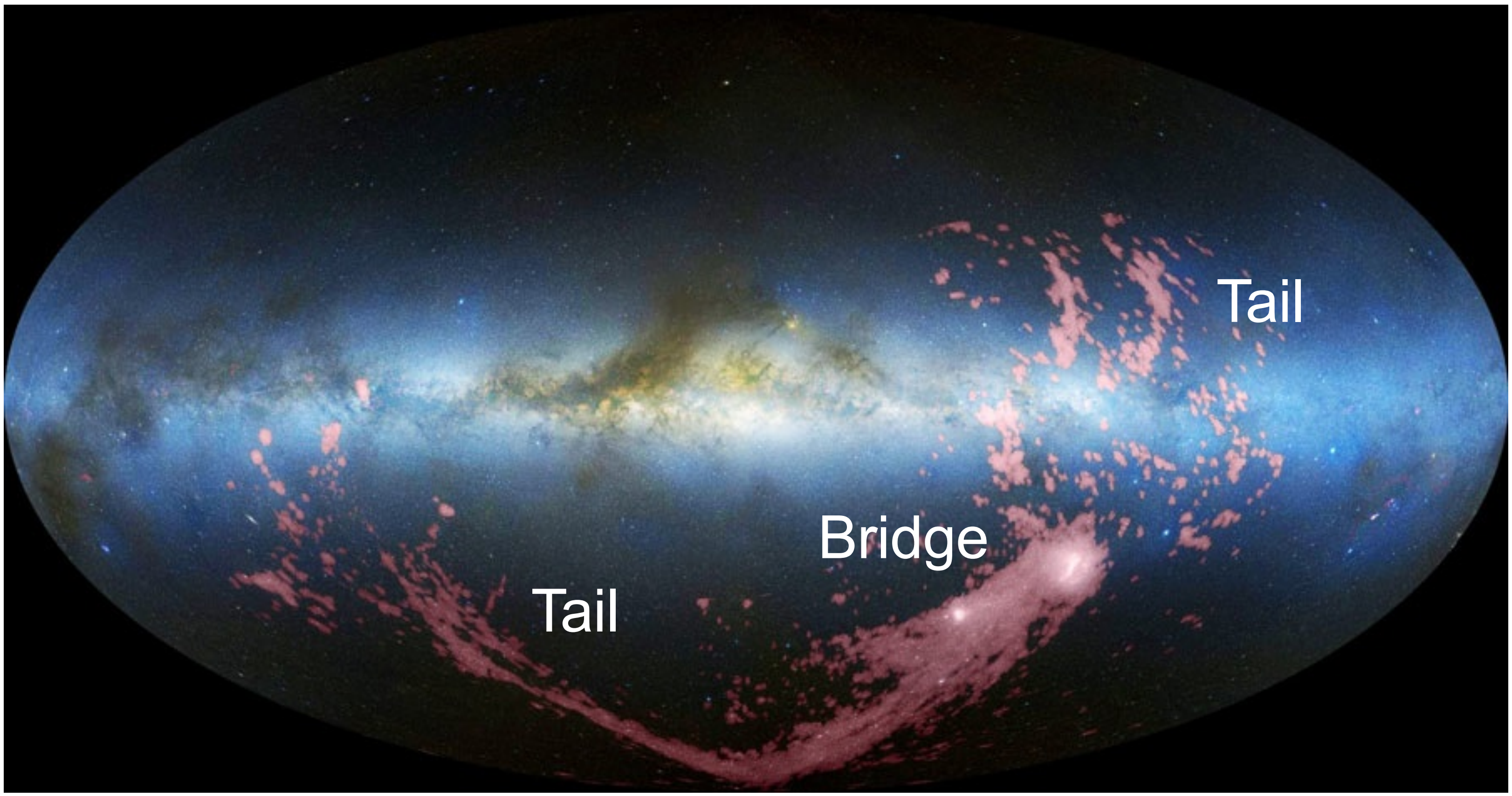
First Measurement of PM Rotation Field

van der Marel & Kallivayalil 2014   1 revolution in ~ 250 Myr

Confirmation of PMs With Gaia



Origin of the Magellanic Stream in a Recent Capture Scenario



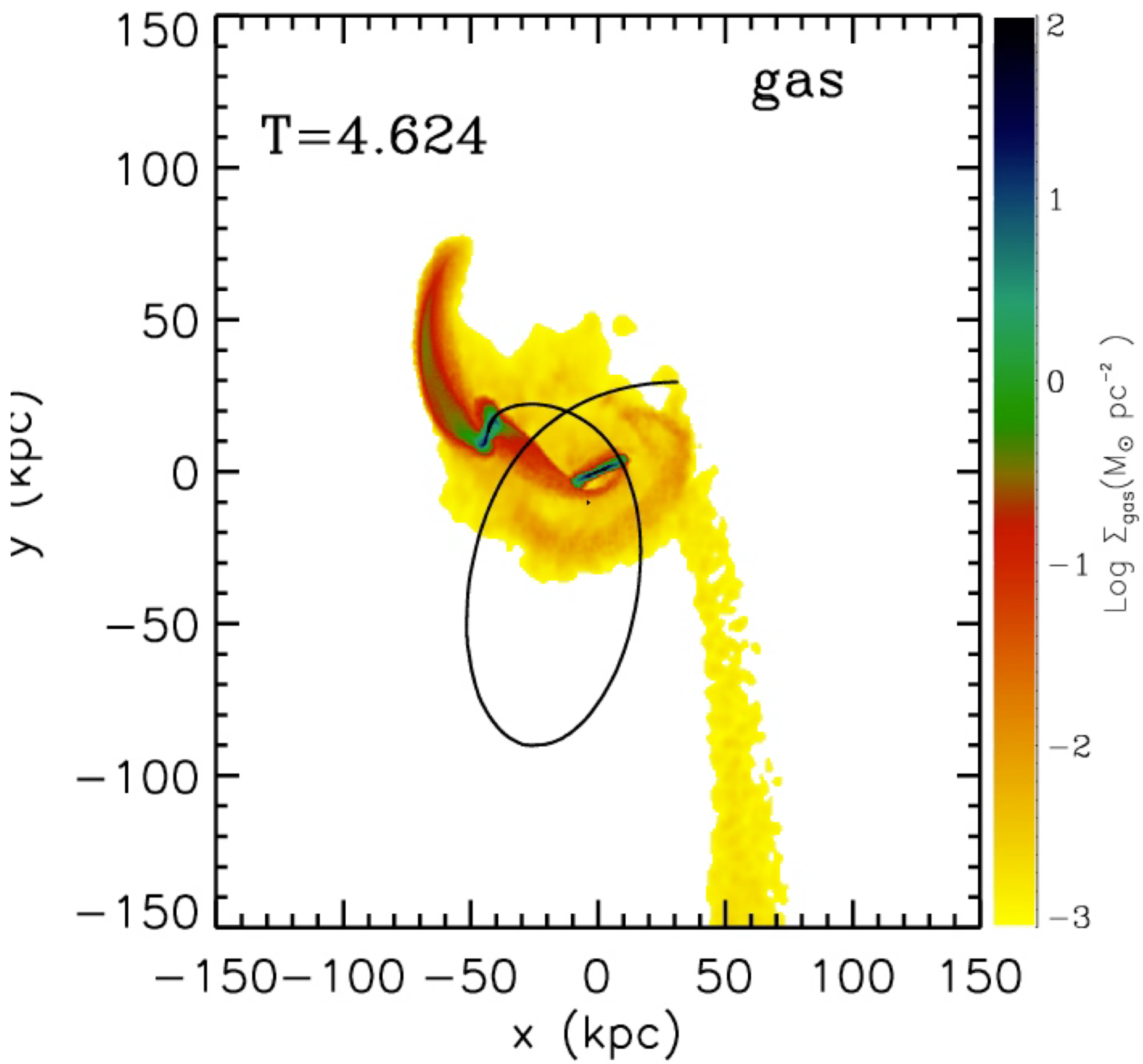
Nidever + 2008

Galactic Collisions Produce Bridges and Tails

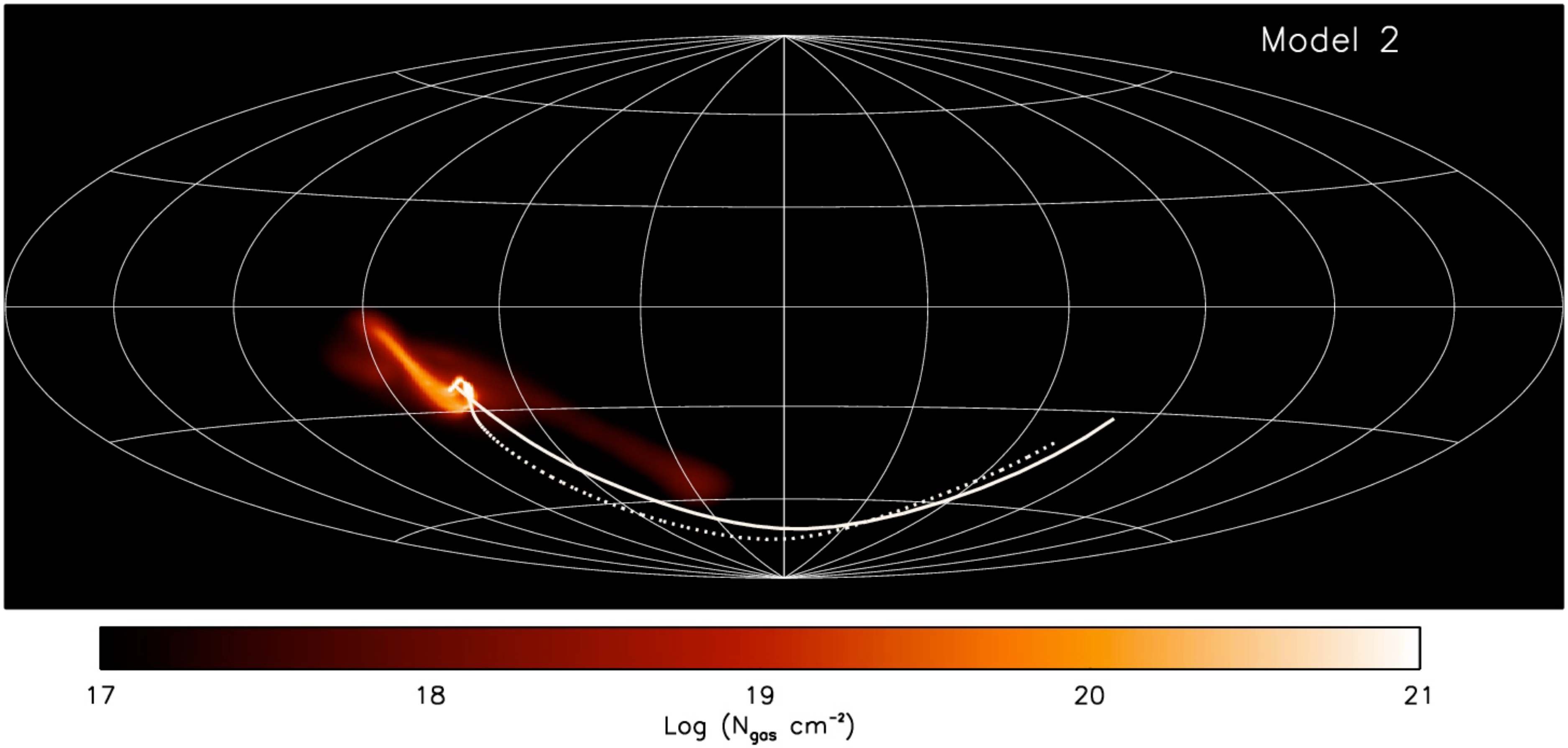
Computer Simulation

Hubble Image

The SMC - LMC Interactions Before Capture by the Milky Way

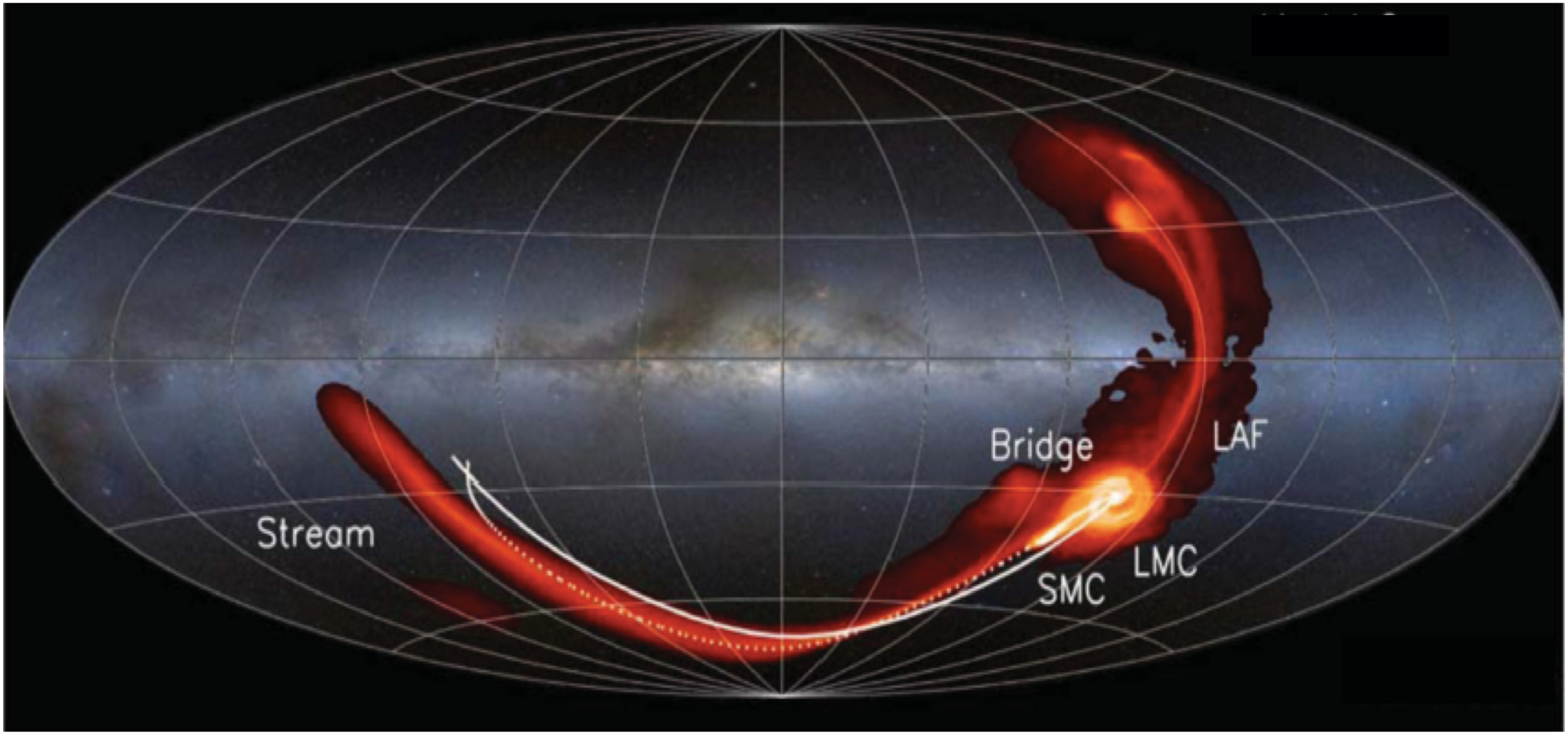


The Formation of the Magellanic Stream
(after capture)



Besla + 2010, 2012

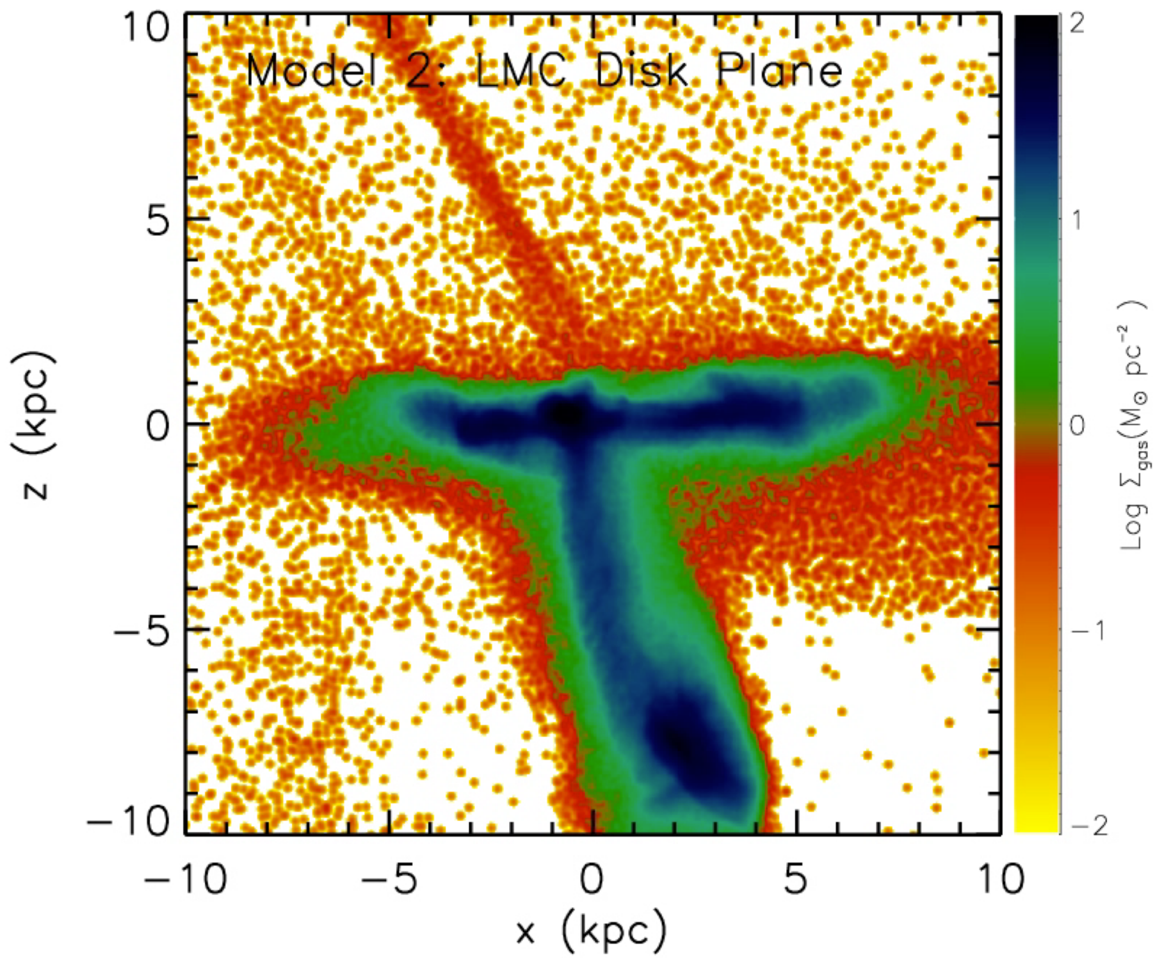
Simulation Results

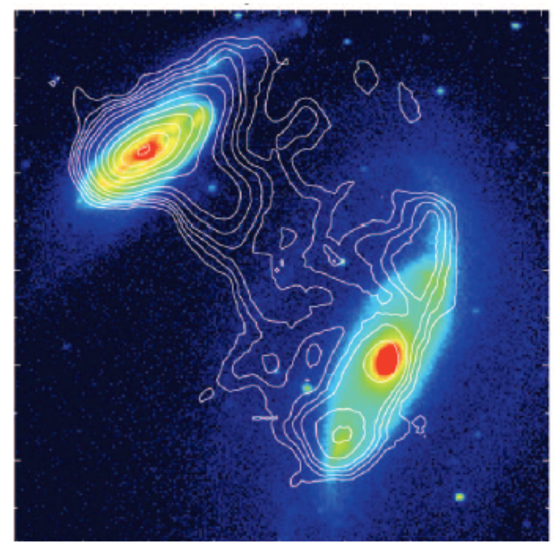


Interactions between the Clouds formed the Stream.
Maybe they came in with companions?

A recent LMC-SMC collision

The Bridge forms from ram pressure & tidal stripping of the SMC during its passage through the LMC's gaseous disk: Bridge Proposal





Taffy Bridge
Gao et al. 2003

Besla et al. 2012

Components

- **Abstract**
- **Science Justification**
- Technical Justification
  - GO: Observational Strategy
  - AR: Analysis Plan & Management Plan
- **2 pages for figures/references**

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]

- No limits on figures, but total page count matters
- 12 pt font

Outline

- Abstract: Summarizes the entire proposal
- Section 1: Facts and summary of Sections 2-5
- Section 2 : The Problem/Motivation
- Section 3: The Proposal/Target/Goal
- Section 4: Why the Target/Proposal solves the Problem & why that's important
- Section 5: Broader Impacts/Bonus Science

GO Abstract Recipe

Set the stage & be concise !!!!

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

Example GO Program: Proper Motion Field Along the Magellanic Bridge

Abstract

Facts	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
Importance	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.
Goal	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-
Problem	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.
HST Strategy	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.
Broader Impacts	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.

Science Justification: Section 1
The Big Picture

- Use descriptive headings (not “intro”/ “backgrd”)
- 1-3 paragraphs:
  - Explain/Justify “the Facts” stated in abstract
  - Role of HST in establishing facts.
  - Explain the importance of “the Facts”
  - Introduce the “Problem” (to be expanded on)
- <u>Last paragraph (1-2)</u>: (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

1 Cosmological Importance of the Magellanic System

Facts/Info indisputable

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.

Team Expertise & Role of HST in establishing facts

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.

Significance of facts (bigger picture)

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 MWs gaseous halo, so the formation mechanism of such structures is an important mode of gas supply to our MW.

Problem- To be expanded on

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.

Bridge: Last Par. of Section 1

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

Anonymizing: as of 2018

- When citing references within the proposal, use third person neutral wording. This especially applies to self- referencing. For example, replace phrases like “as we have shown in our previous work (Doe et al. 2010)” with “as Doe et al. (2010) showed...” Do not refer to previous campaigns using HST or other observatories in an identifying fashion. For instance, rather than write "we observed another cluster, similar to the one we are proposing under HST program #XXXXX," instead write "HST program #XXXXX has observed this target in the past..."
- We encourage references to published work, including work citable by a DOI. It may be occasionally important to cite proprietary datasets or non-public software that may reveal (or strongly imply) the investigators on the proposal. We suggest proposers use language like "**obtained in private communication" or "from private consultation**" when referring to such potentially revealing work.
- Do not include acknowledgements, or the source of any grant funding.
- It is not necessary to "water down" or obscure your science, your methods, or your tools; it is simply your responsibility to write about them in the third-person, in a way that does not intentionally identify yourself

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
- Identify “the key component” of “the problem” (be specific – well contained problem)
- Explain why “the key component” is crucial

Section 2. "Key Component" – impact parameter

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 ($R_{sep} \lesssim 10$ kpc) to a complete miss ($10 \lesssim R_{sep} \lesssim 20$ kpc) (Kallivayalil et al. 2013). 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 Besla et al. (2012) 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.

The Problem

The "KEY COMPONENT"

Science Justification: Section 3 The Target & Plan -- Feasibility of HST Obs.

- Introduce the object/target (**broadly**) and why it is important.
- Why does your target solve the problem (what is the *KEY COMPONENT*)?
- What are the specific targets of the observations and why? A figure can help here
- Why will HST be able to observe the target (point to existing data, or sensitivity limits)

3 The Magellanic Bridge

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.

The Target & Importance

Why Target will solve the problem – reveals the "KEY COMPONENT"

Target Specifics & HST Feasibility – existing data, previous strategies

Justify target choice

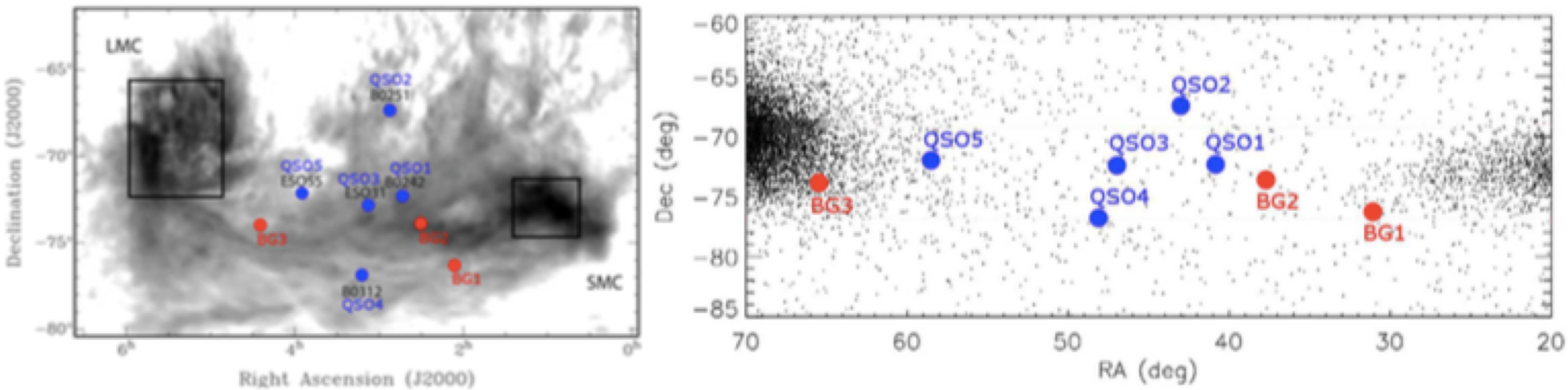
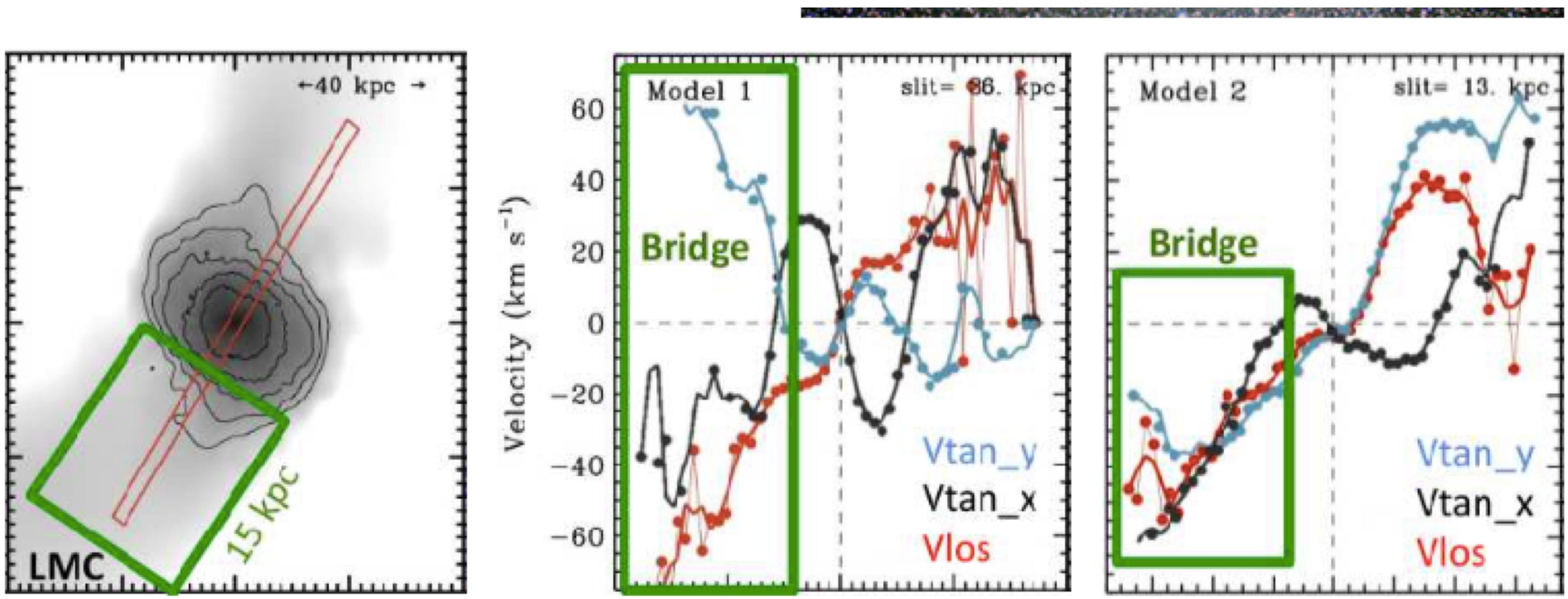


Figure 1 (left) HI map of the Magellanic System (Brüns et al. 2005). The boxed areas on the left and right are centered on the LMC and SMC, respectively, and indicate the regions for we have already mapped the PM field with HST (see e.g. Fig. 4). We propose to target the labeled fields to map for the first time the PM field of the Magellanic Bridge between the Clouds.

Science Justification: Section 4 The Target and “The Problem”

- Show how the observations will address ‘the problem’ -- a Figure can help here.
- *STATE* that it will solve the problem.
- Describe some extra science related to the target.

How HST will solve the problem



Science Justification: Section 5
Big Picture Implications

- How does the observations help other science? “shed new light” on another problem?
- Other uses for the data set (legacy value) - ”gold standard” techniques, benchmark, etc.

stars should be part of the same complex that makes up the Magellanic Bridge. Our PM measurements will allow us to test this for kinematical consistency. *Our measurements will therefore also shed new light on the presence of tidally disrupted material throughout the Magellanic system, and the hypothesis that it is responsible for the observed microlensing events.*

- 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

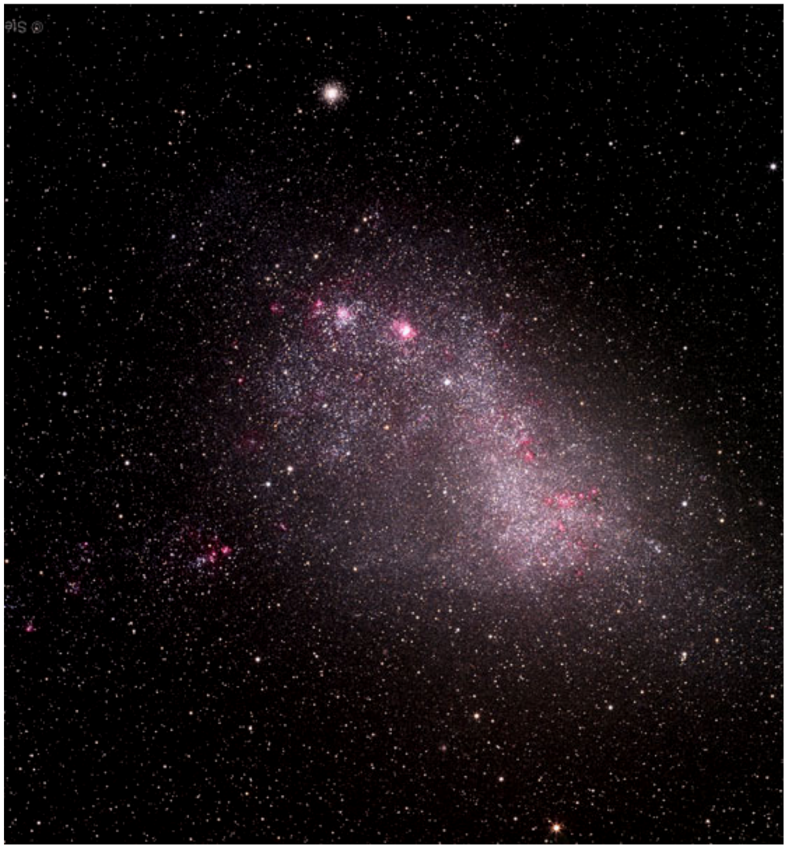
For GO: describe the proposed observations briefly

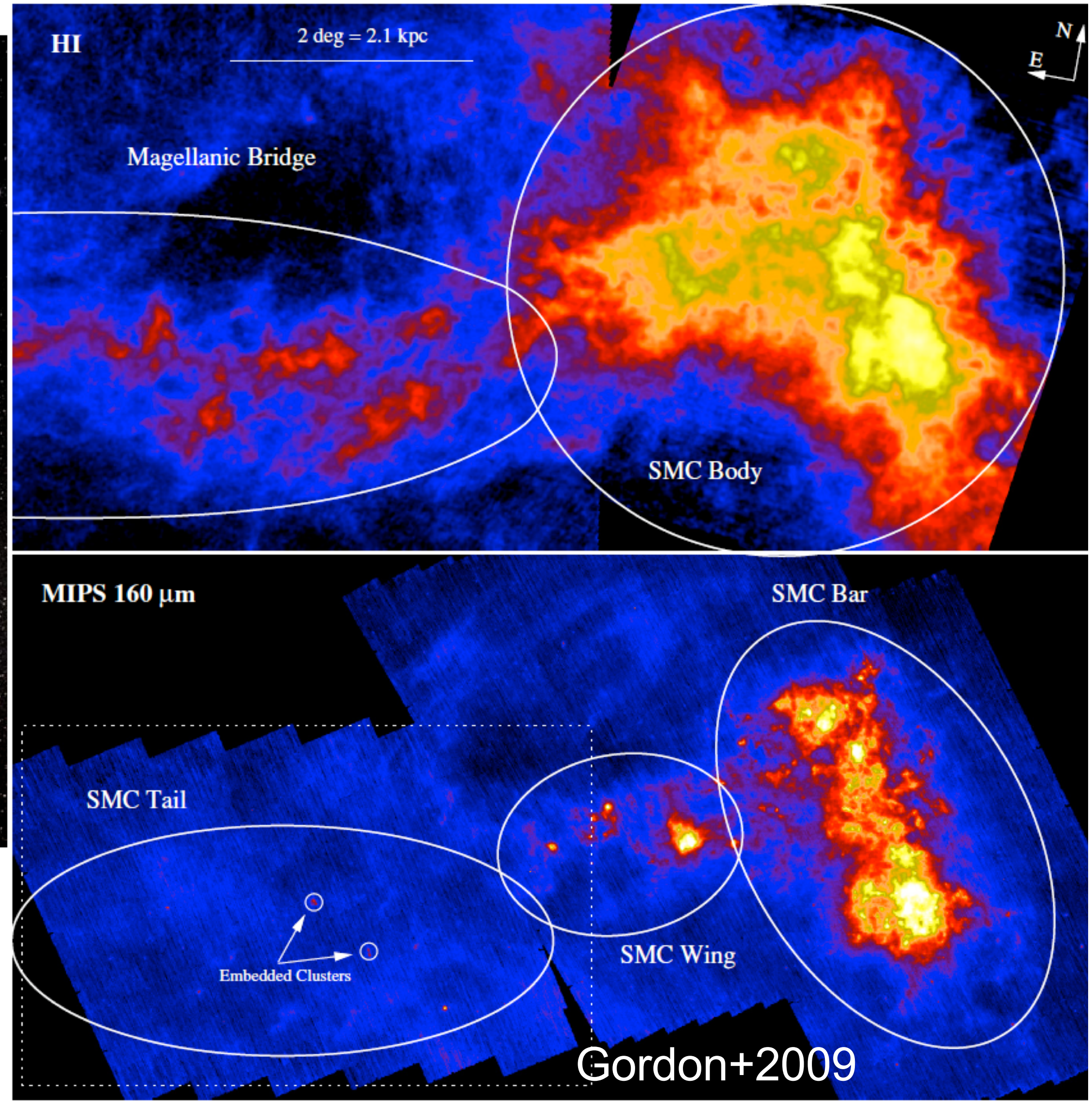
For AR: describe the analysis method briefly

- Section 5: Broader Implications

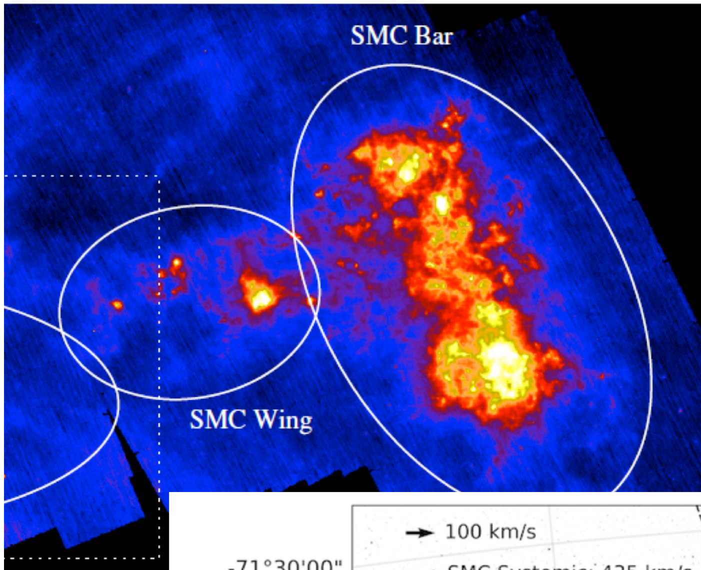
For AR: indicate that new data products will advance the field

Kinematics of the SMC with HST and Gaia DR2

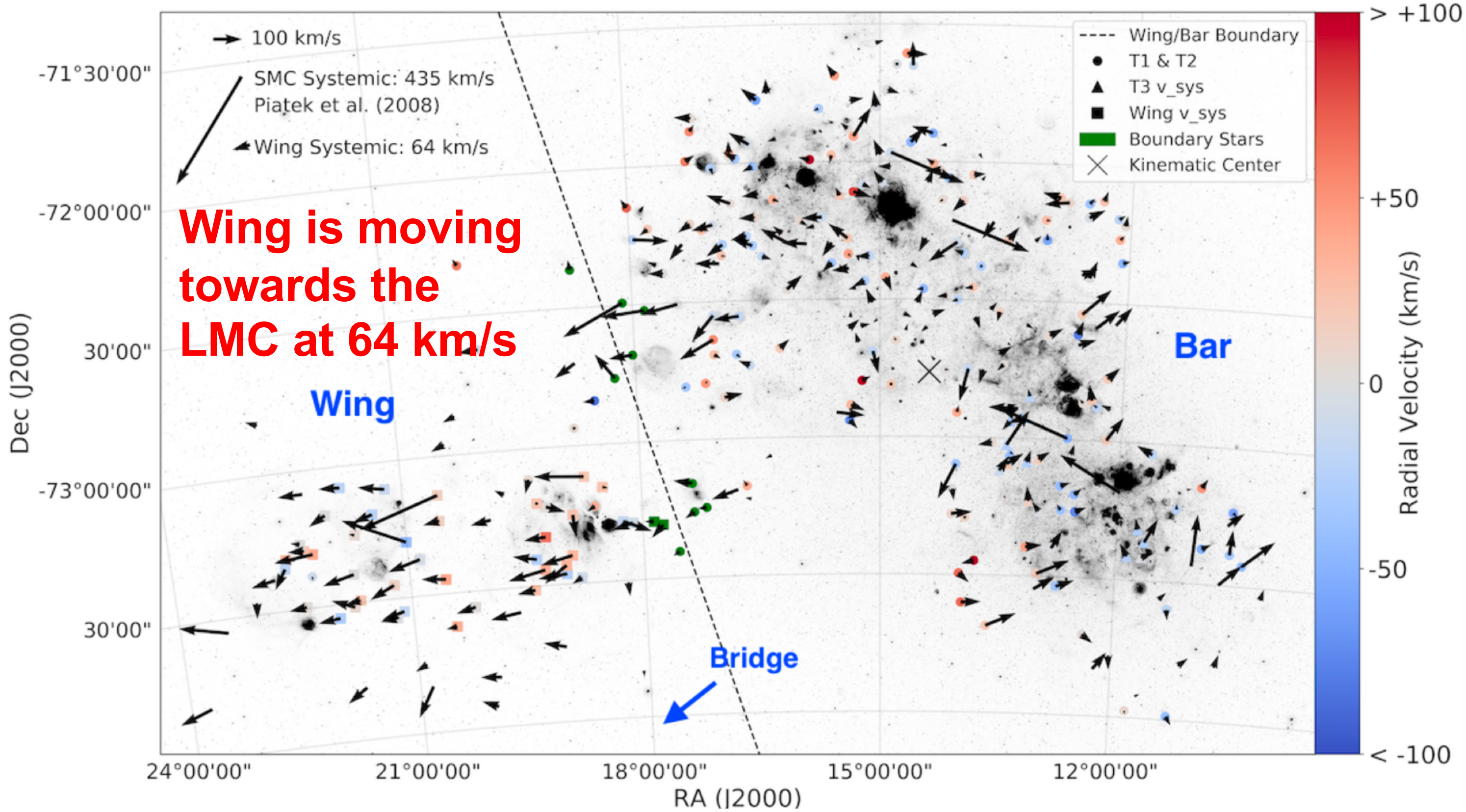




Kinematics of the SMC with HST and Gaia DR2



Oey (with GB) + 2018



Zivick, Kallivayalil, Besla+2018