Exploring Magellanic Interactions Through Bridge and Small Magellanic Cloud Dynamics

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Motivation

- SMC-LMC system provides the closest example of interacting dwarf galaxies
  - Evidence of significant interaction
    - HI studies (e.g., Putman et al. 2003)
    - Potential tidal features in old stars (e.g. Belokurov et al. 2017, Jacyszyn-Dobrzeniecka et al. 2018)
    - Young star formation in the Magellanic Bridge (e.g. Skowron et al. 2014)

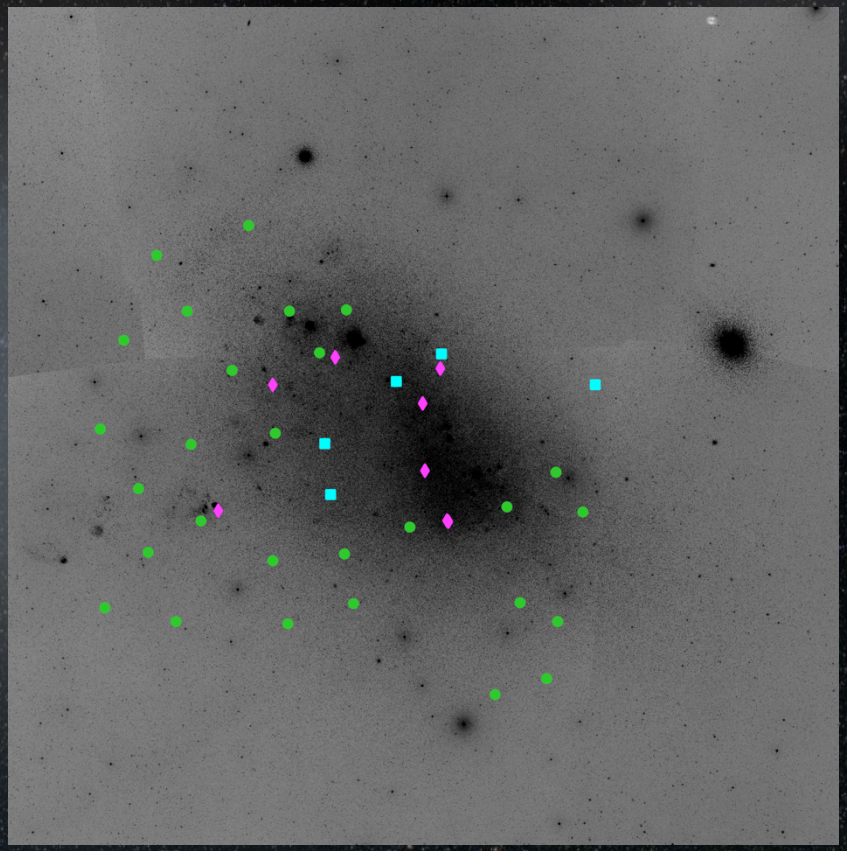
- The addition of kinematics to the picture will dramatically increase our understanding.

SMC Dynamics (Pre-DR2)

- Complex 3D structure (e.g. Jacyszyn-Dobrzeniecka et al. 2018, Ripepi et al. 2017, Muraveva et al. 2017)
- Multiple models for potential rotation (or lack thereof) in the SMC (e.g. Stanimirović et al. 2004, Evans & Howarth 2008, Dobbie et al. 2014)
- Relatively few proper motion measurements for SMC
  - *HST* (Kallivayalil et al. 2013)
  - van der Marel & Sahlmann 2016 (using TGAS from Lindegren et al. 2016)

SMC Dynamics (Pre-DR2)

- *HST* measurements of the proper motions in the SMC (Zivick et al. 2018)



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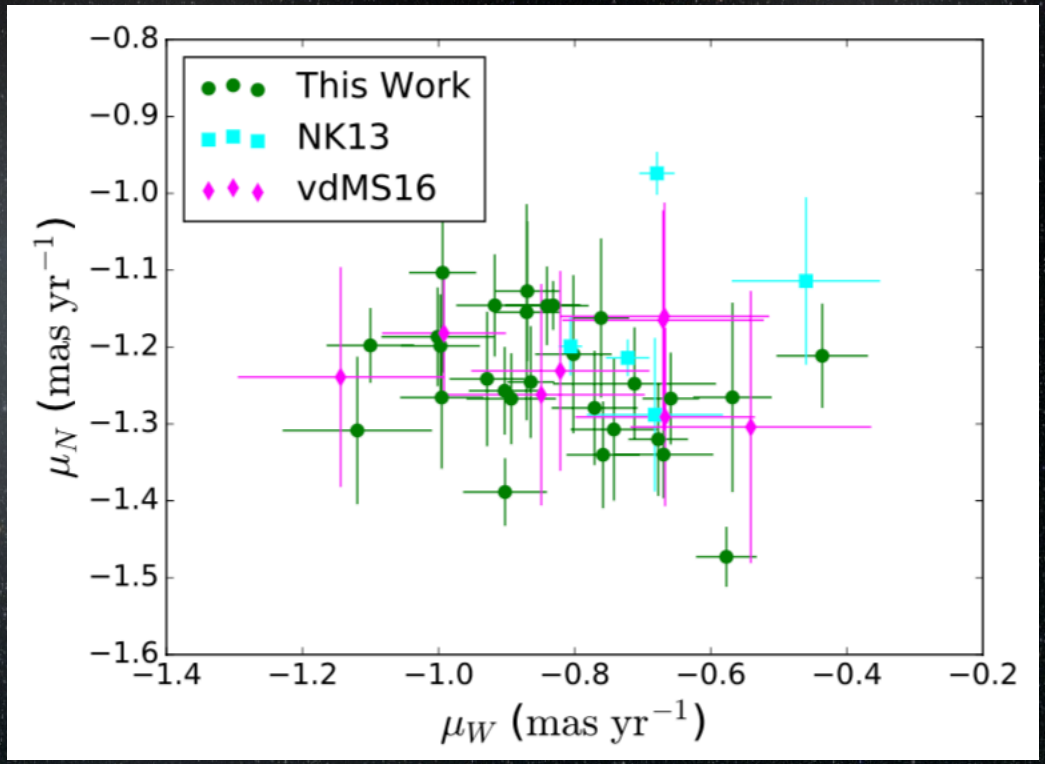

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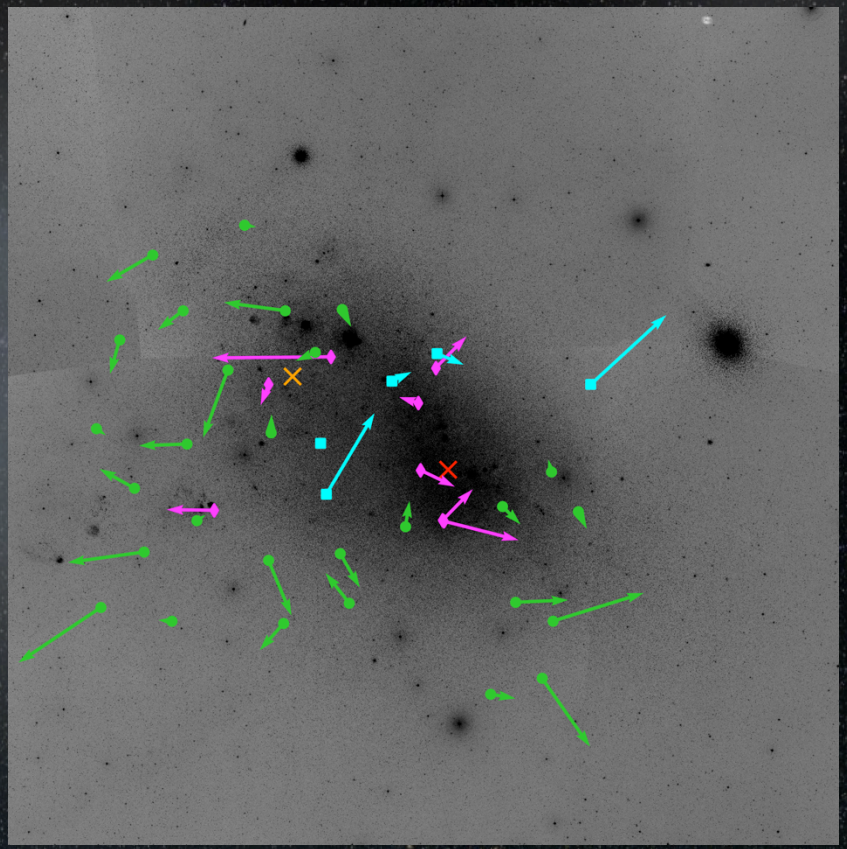

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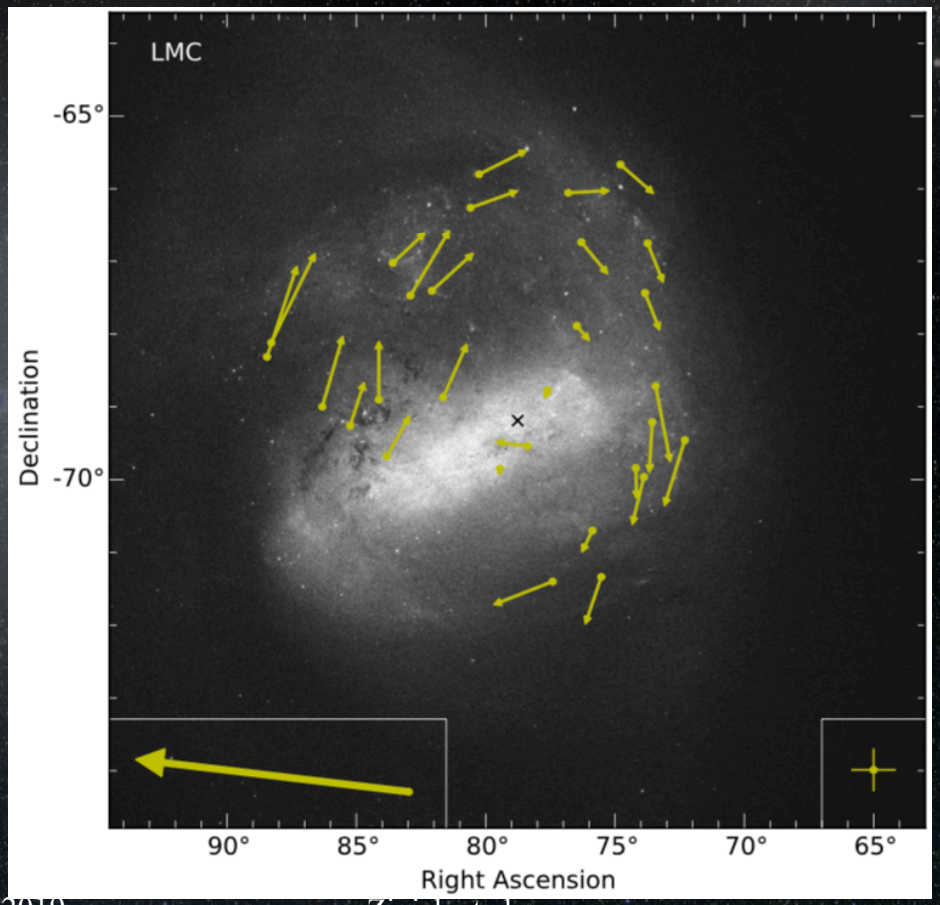

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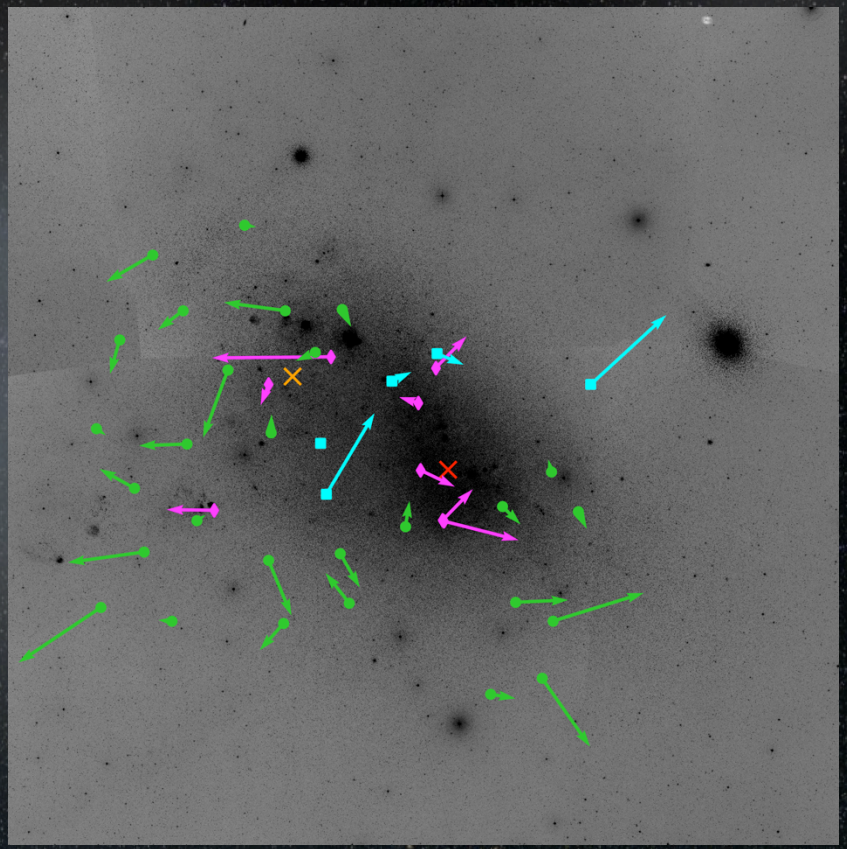
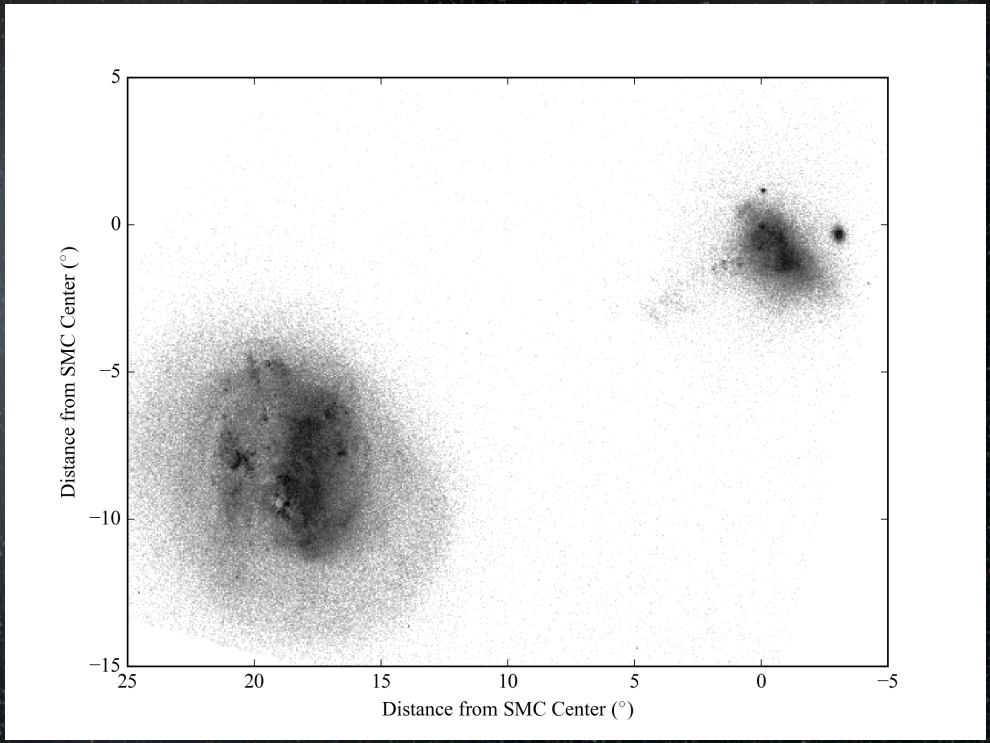


SMC Dynamics (Pre-DR2)

- Summary of results:
  - Demonstrated coherent radial motion outwards in the outskirts of the SMC
  - With improved precision on systemic properties of SMC, constrain average interaction history to ~9 kpc separation happening ~150 Myr ago.

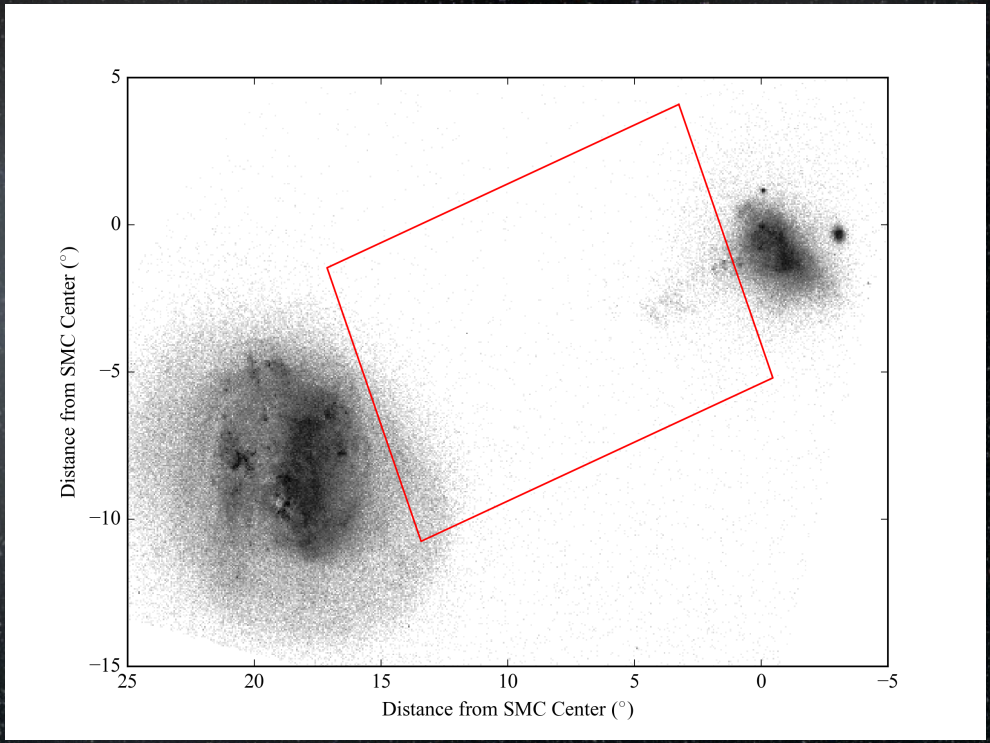
The Clouds as Seen by *Gaia*

- The advent of *Gaia* DR2 significantly expanded our kinematic picture of the Clouds



The Magellanic Bridge

- Applied *Gaia* Data Release 2 to the Bridge region to study its kinematics (Zivick et al. 2019)

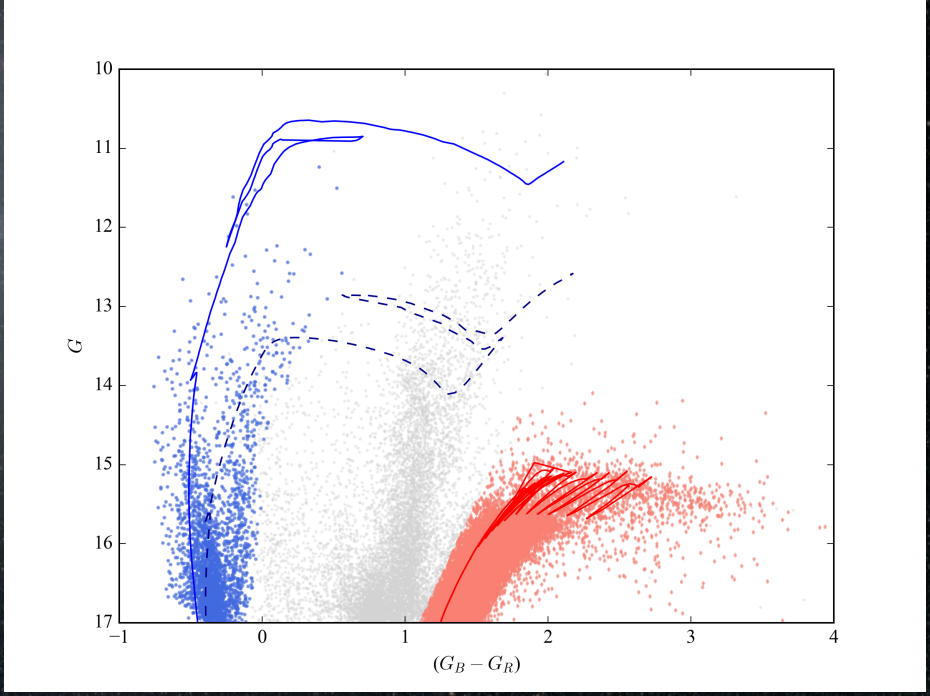


The Magellanic Bridge

- For selecting stars in the Magellanic system, we use the criteria of:
  - Parallax < 0.2 mas
  - RUWE < 1.40 (Gaia technical note GAIA-C3-TN-LU-LL-124-01)
  - Color excess criteria (Lindegren et al. 2018)

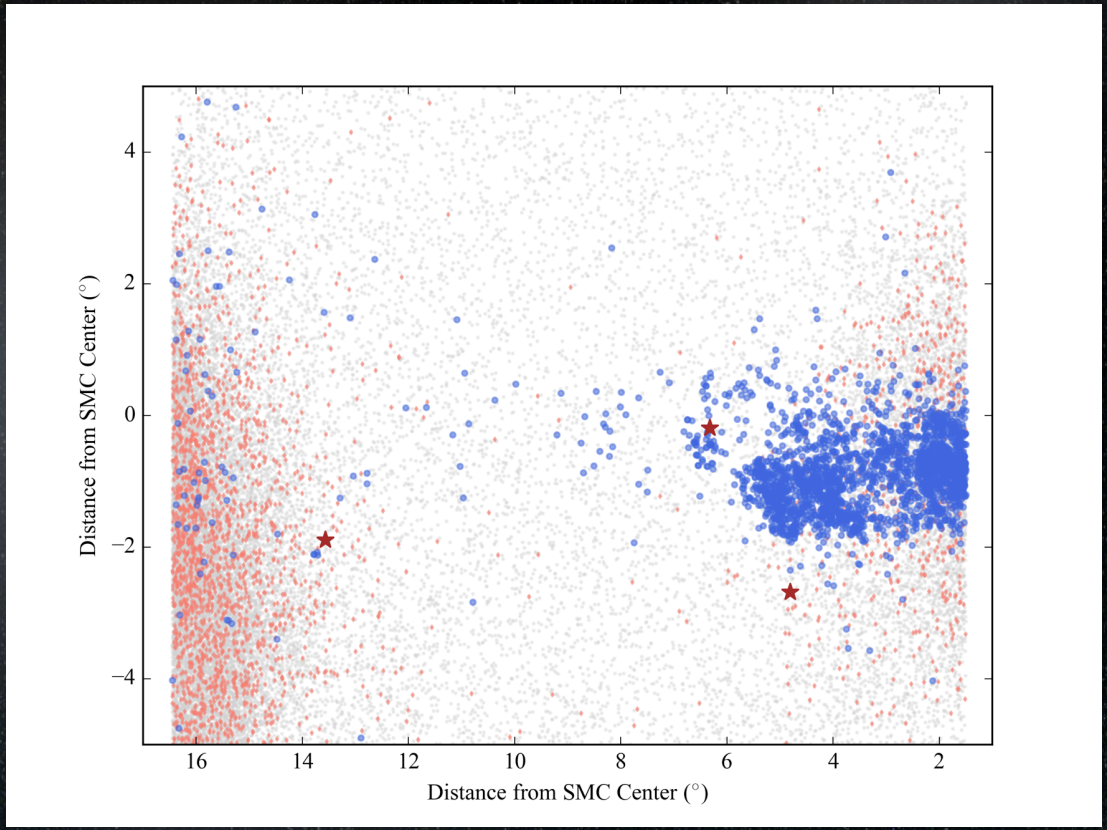
The Magellanic Bridge

- Two distinct stellar features appear in the selected region:
  - Main sequence stars consistent with ~10 Myr ages
  - RGB stars consistent with >1 Gyr ages



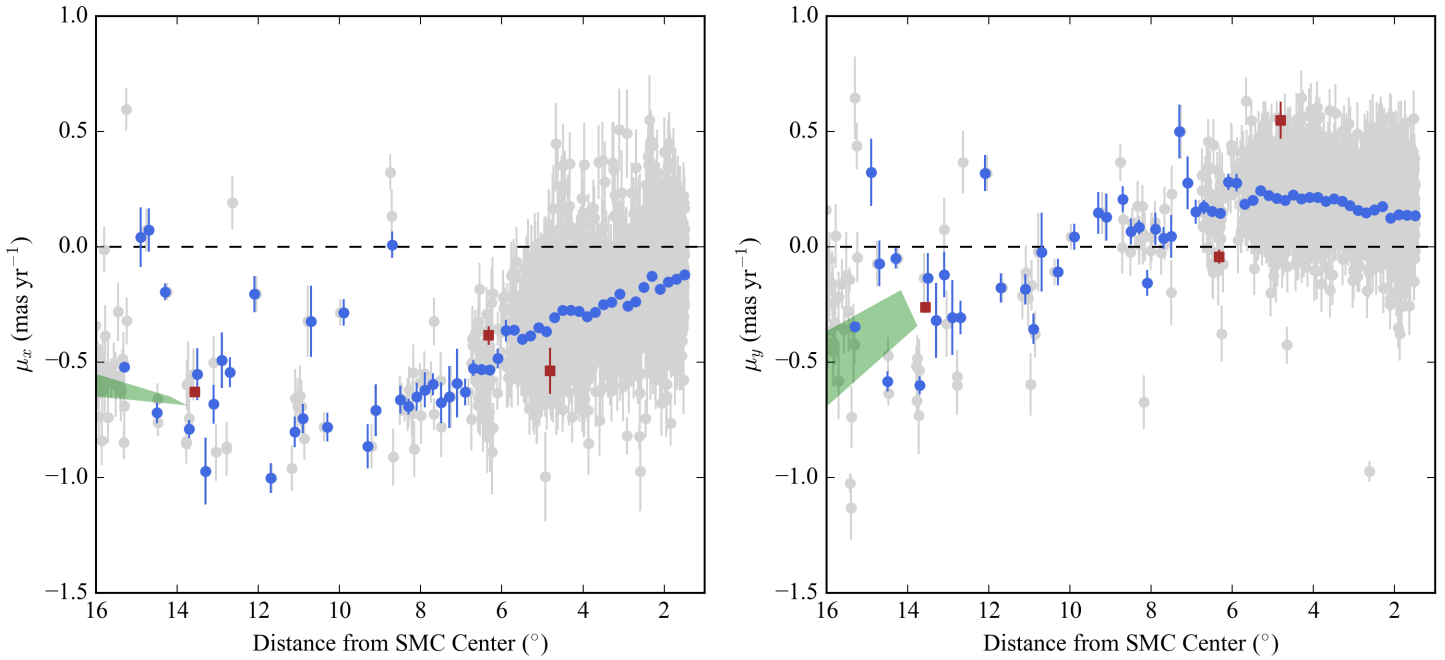
The Magellanic Bridge

- Clear and distinct spatial distributions for each sequence



The Magellanic Bridge

- Both stellar features reveal clear and ordered behavior in their kinematics



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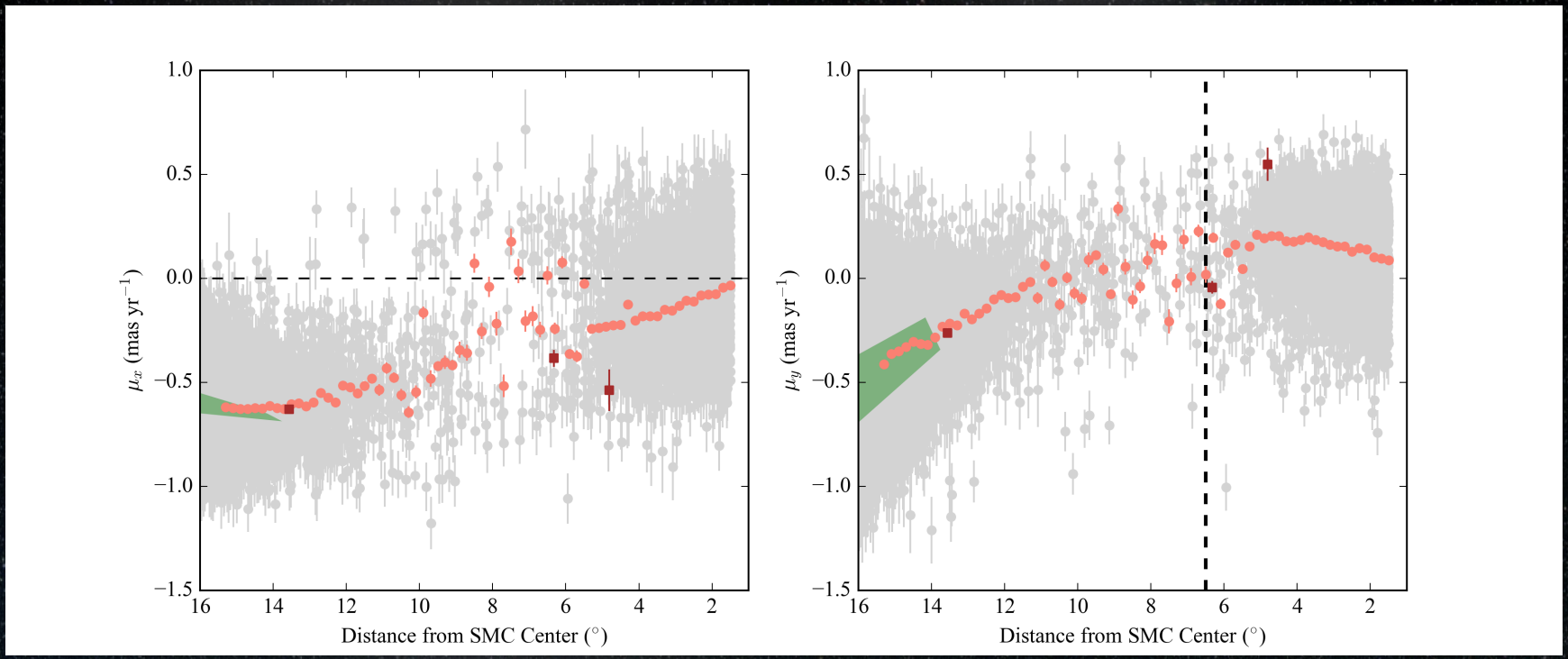
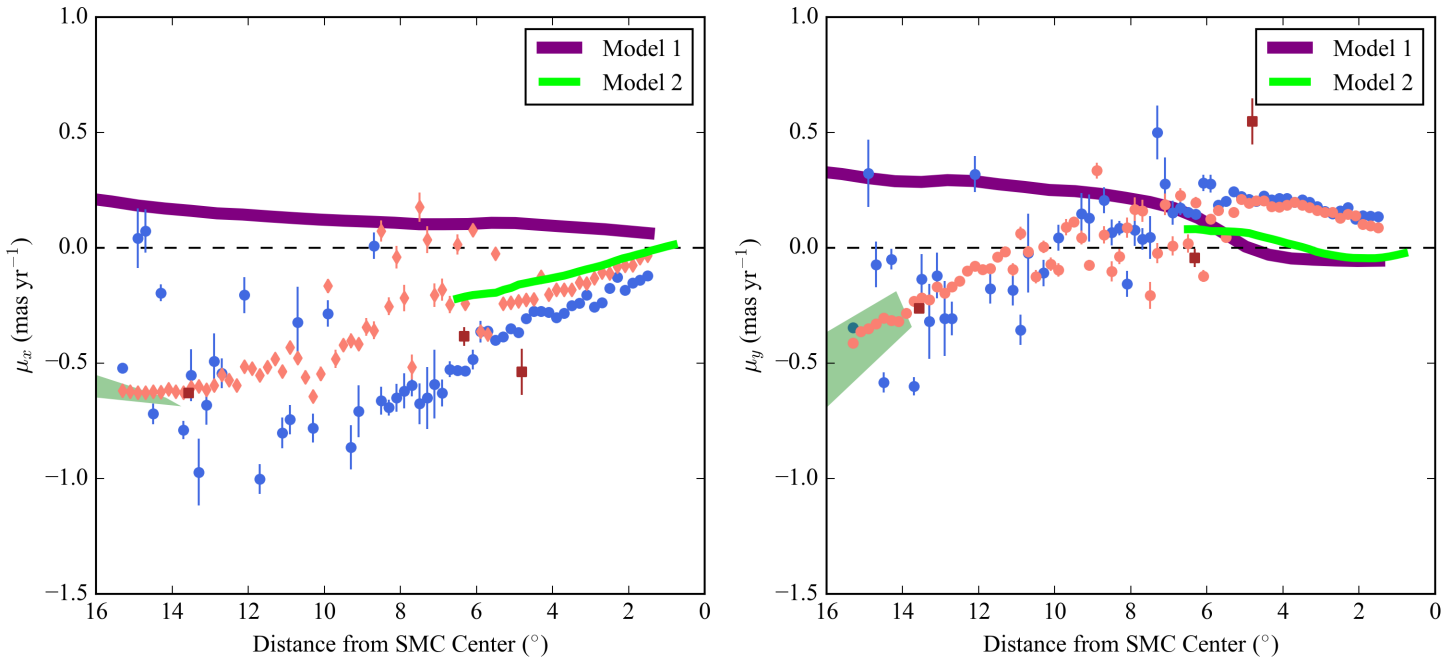


The Magellanic Bridge

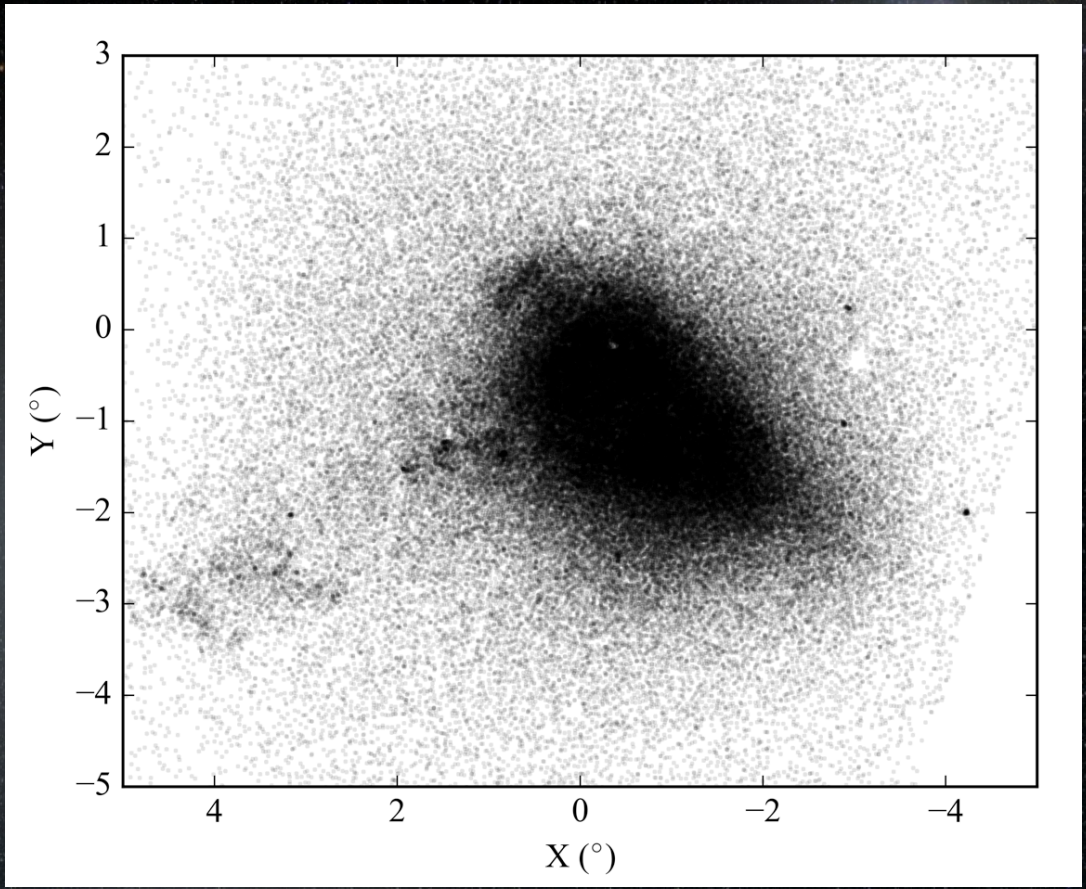
- Comparison to simulated Magellanic interaction histories
  - Model 1:
    - ~20 kpc minimum separation
    - Primarily tidal interactions
  - Model 2:
    - ~2 kpc minimum separation
    - Ram pressure stripping of gas in addition to tidal interactions

The Magellanic Bridge

- Clear departure from predictions in the data

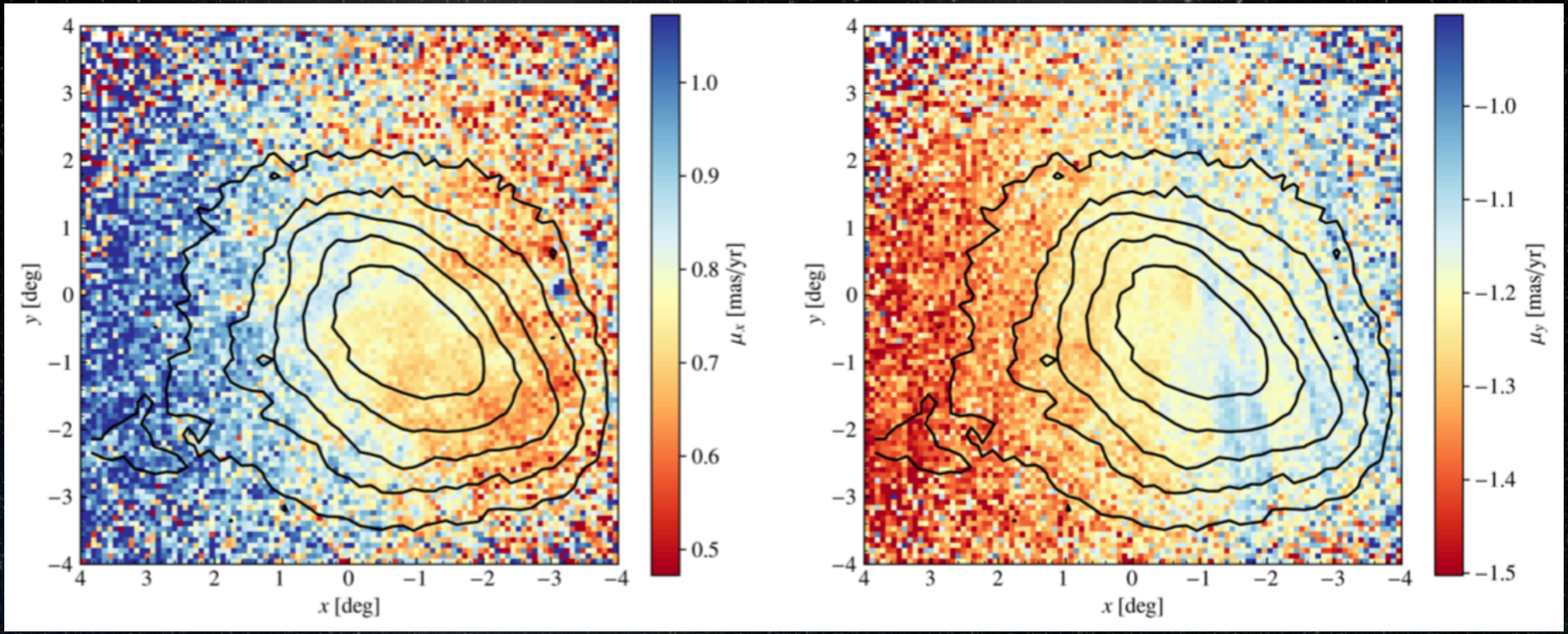


SMC Dynamics (Post DR2)



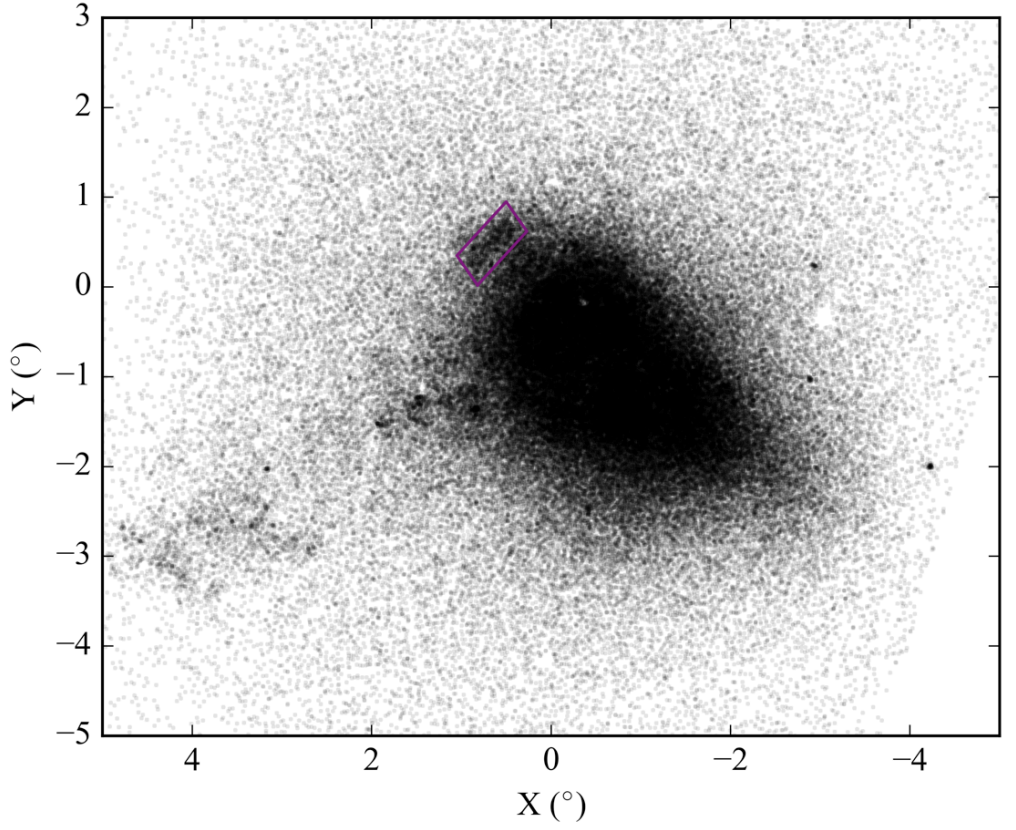
SMC Dynamics (Post DR2)

- Initial DR2 analysis did not reveal any obvious rotation (Gaia Collaboration, Helmi et al. 2018)



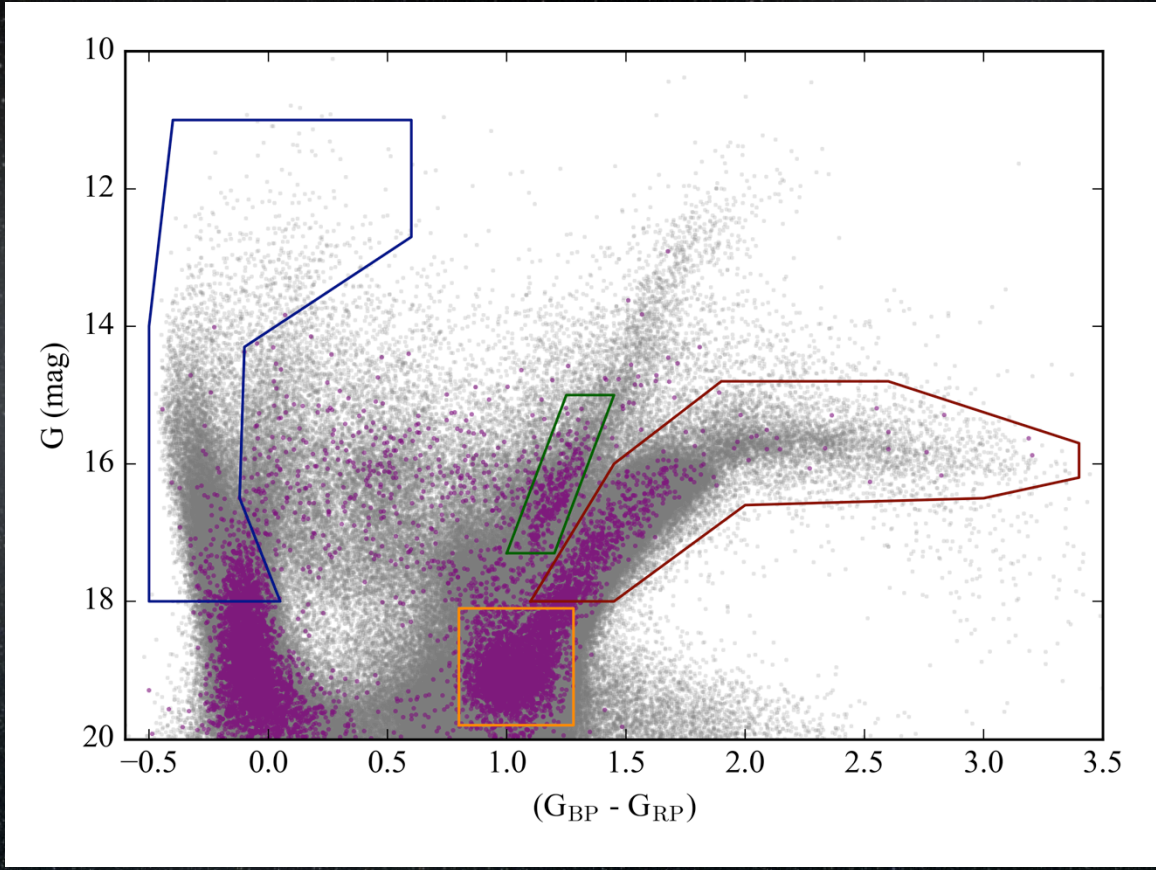
SMC Dynamics (Post DR2)

- Decided to investigate optical substructures using DR2 (Martinez-Delgado et al., in prep)



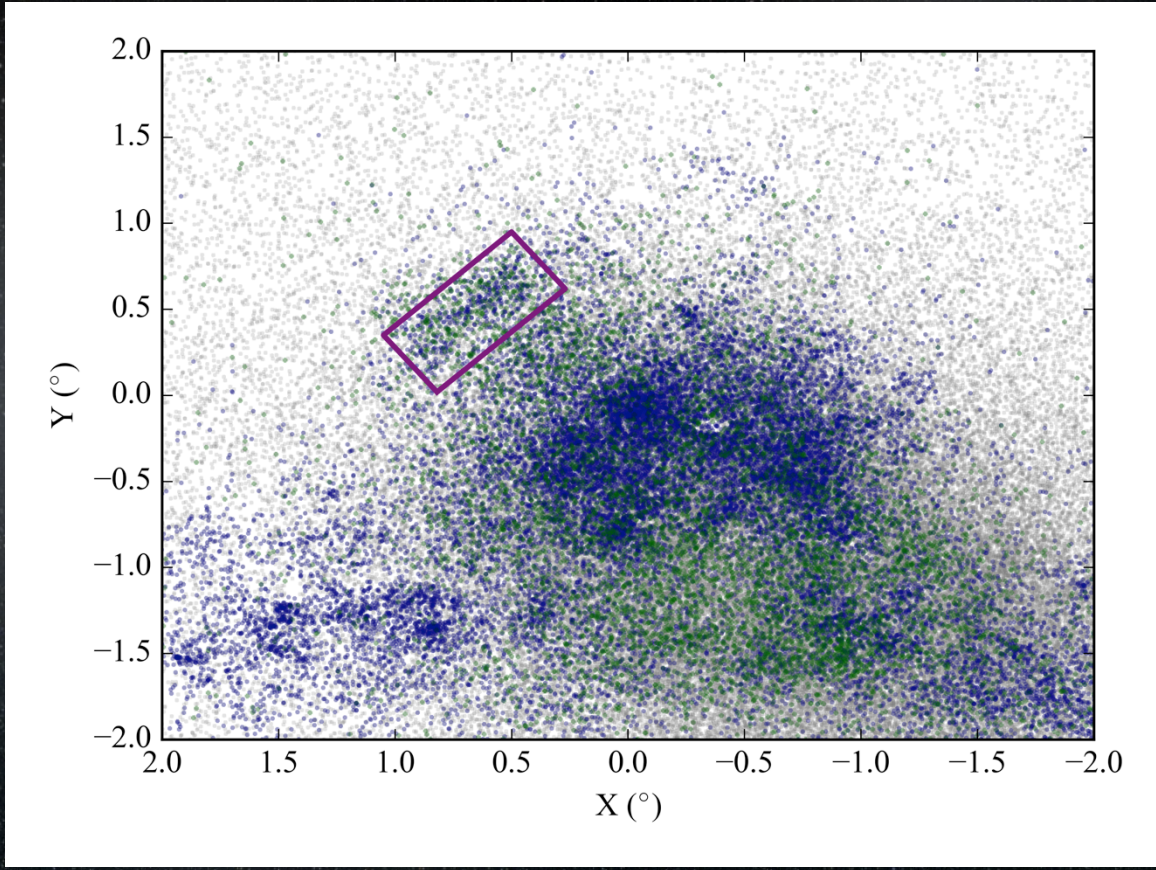
SMC Dynamics (Post DR2)

- Identified different stellar features for examination



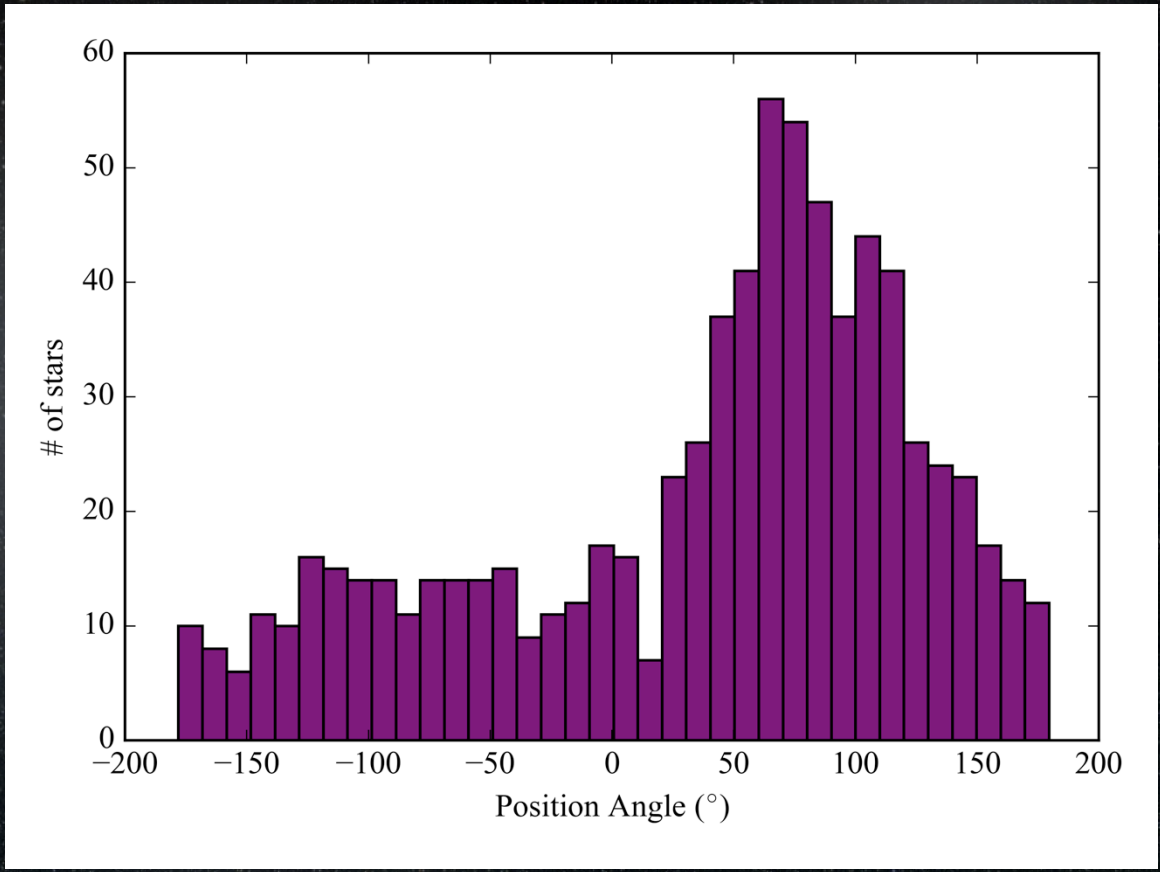
SMC Dynamics (Post DR2)

- Main sequence and red supergiants comprise shell-feature



SMC Dynamics (Post DR2)

- Clear trend in position angle of residual vectors



Conclusions

- Kinematics provide new constraints on the Magellanic history
  - Average separations of ~9 kpc and time of last interaction of ~150 Myr
- New analysis of Bridge data supports this close interaction scenario and potentially identifies distinct tidal features
- Broad rotation structure is unclear but substructure does exist in the SMC kinematics